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GENERAL ELECTRIC
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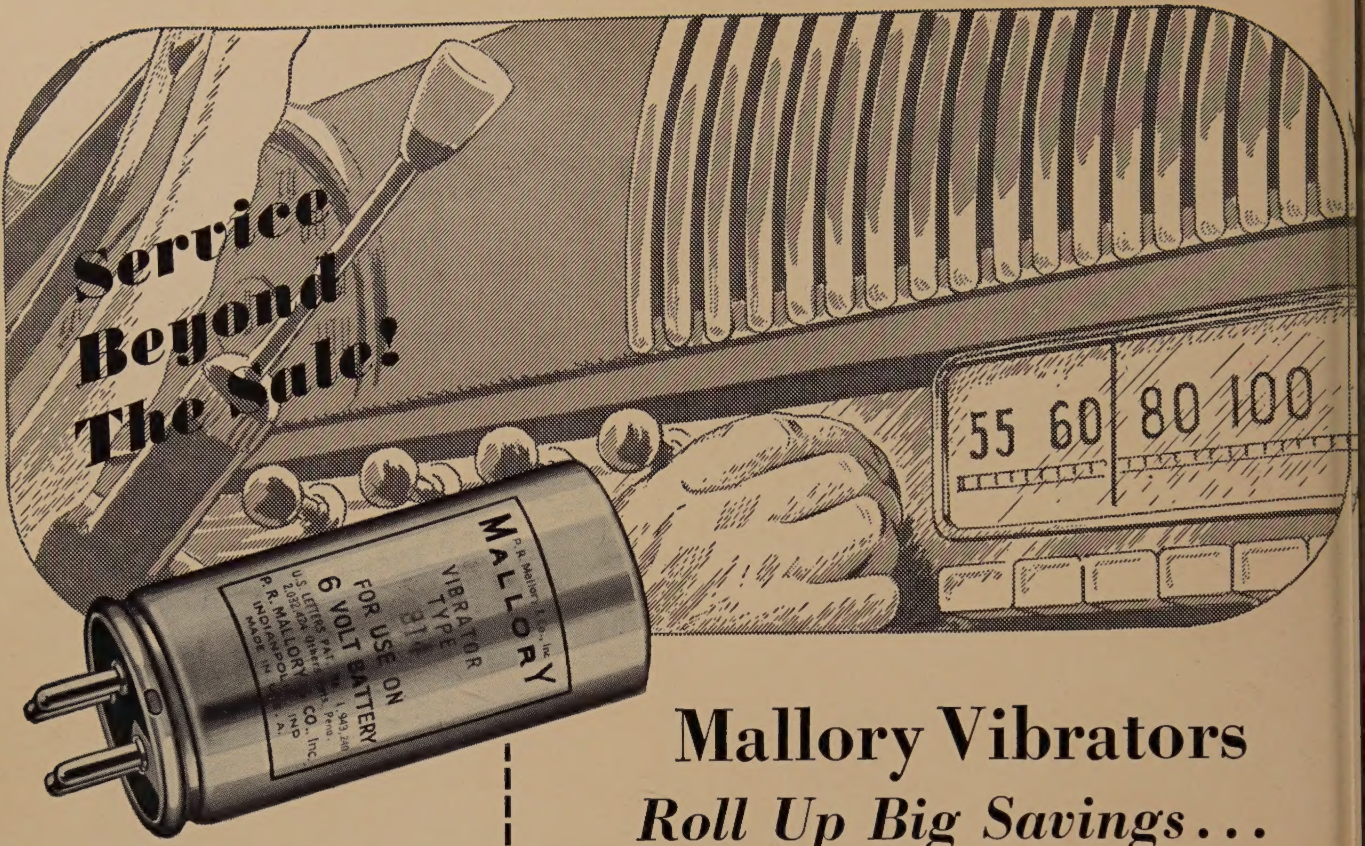
October 1950



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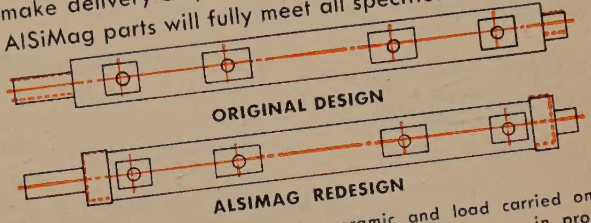

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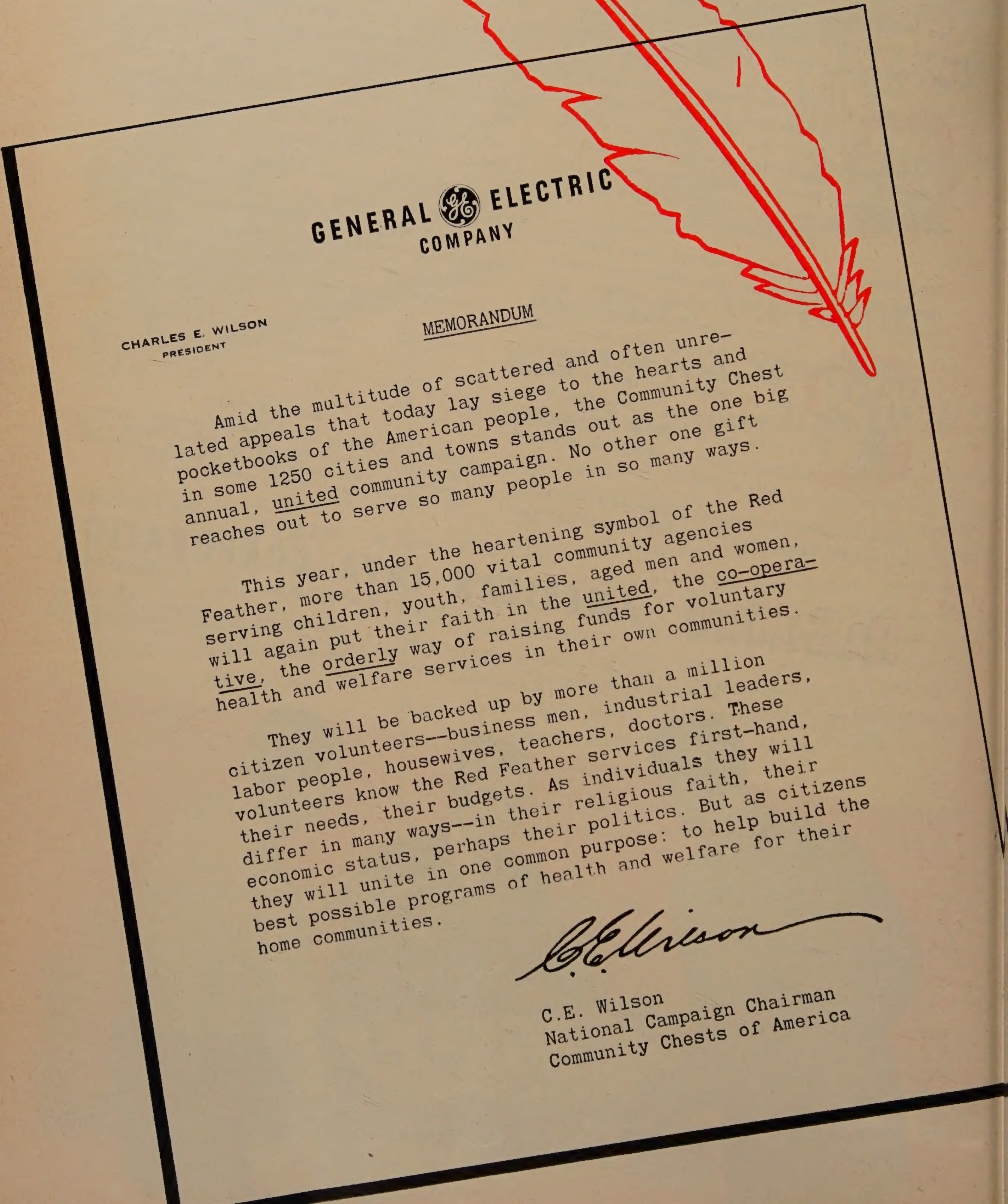
Red Feather Campaigns in 1950



GENERAL ELECTRIC COMPANY

CHARLES E. WILSON
PRESIDENT

MEMORANDUM

Amid the multitude of scattered and often unrelated appeals that today lay siege to the hearts and pocketbooks of the American people, the Community Chest in some 1250 cities and towns stands out as the one big annual, united community campaign. No other one gift reaches out to serve so many people in so many ways.

This year, under the heartening symbol of the Red Feather, more than 15,000 vital community agencies serving children, youth, families, aged men and women, will again put their faith in the united, the co-operative, the orderly way of raising funds for voluntary health and welfare services in their own communities.

They will be backed up by more than a million citizen volunteers--business men, industrial leaders, labor people, housewives, teachers, doctors. These volunteers know the Red Feather services first-hand, their needs, their budgets. As individuals they will differ in many ways--in their religious faith, their economic status, perhaps their politics. But as citizens they will unite in one common purpose: to help build the best possible programs of health and welfare for their home communities.

C.E. Wilson

C.E. Wilson
National Campaign Chairman
Community Chests of America

GENERAL ELECTRIC Review

OCTOBER 1950
Vol. 53, No. 10

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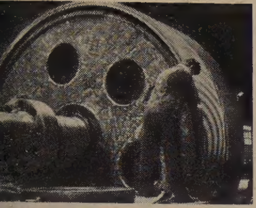

THE COVER

The recently launched liner SS *President Jackson* powered by cross-compound turbines that are uipped with double-reduction articulated-type ars to deliver 12,500 shp at 92 rpm through the assive bull gear shown. Three 600-kw ship's-rvice turbine-generator sets, of a new design nploying three-point suspension, will supply xiliary power and also power for lights, switch-ards, and other electrical equipment. The *Presi-nt Jackson* and her sister ships *President Adams* d *President Hayes* will together use nearly a ousand motors when fully equipped.

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ELECTRONICS

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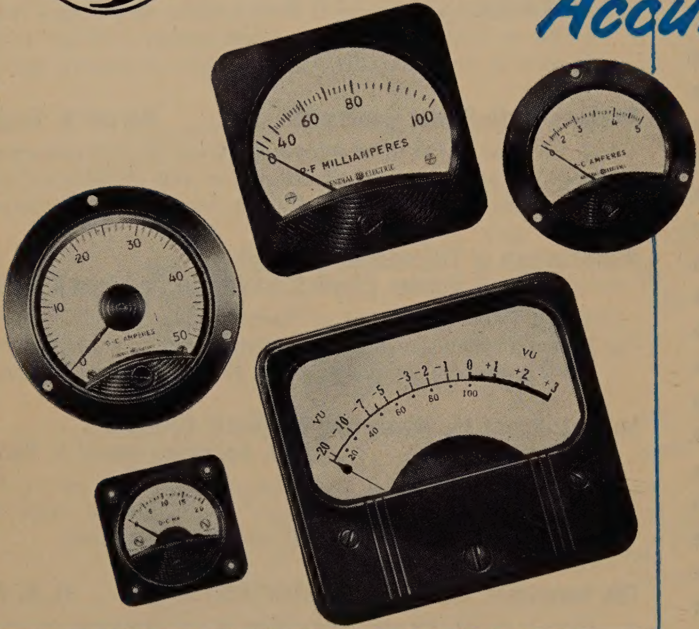

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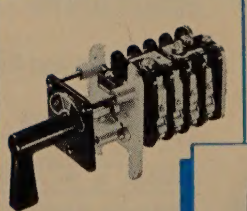
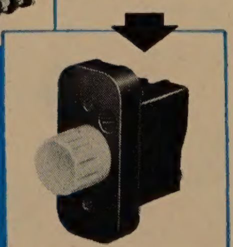


SB-1 switch, cover-removed

Illuminated push button



SAVE PANEL SPACE WITH ONE-UNIT PUSH-BUTTON AND INDICATING LIGHT

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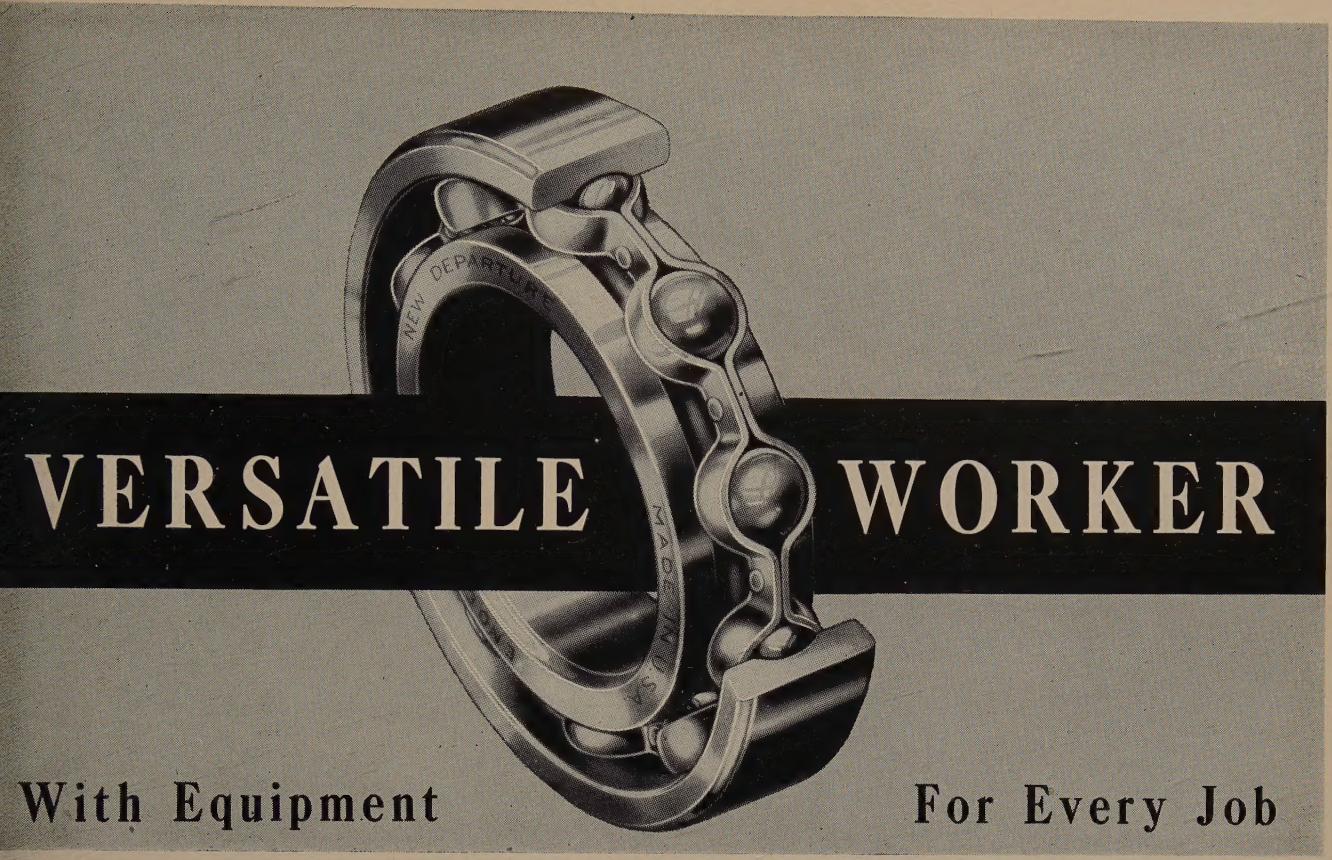
GENERAL ELECTRIC



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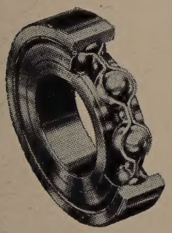
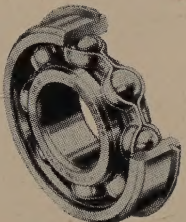
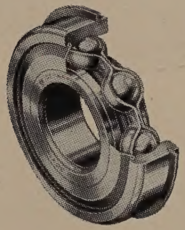


With shield on one side for protection against abrasive dirt.

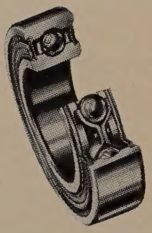
With shields on both sides to keep dirt out and lubricant in.



With snap ring for location of bearing in housing.



With snap ring and either one or two shields as required.



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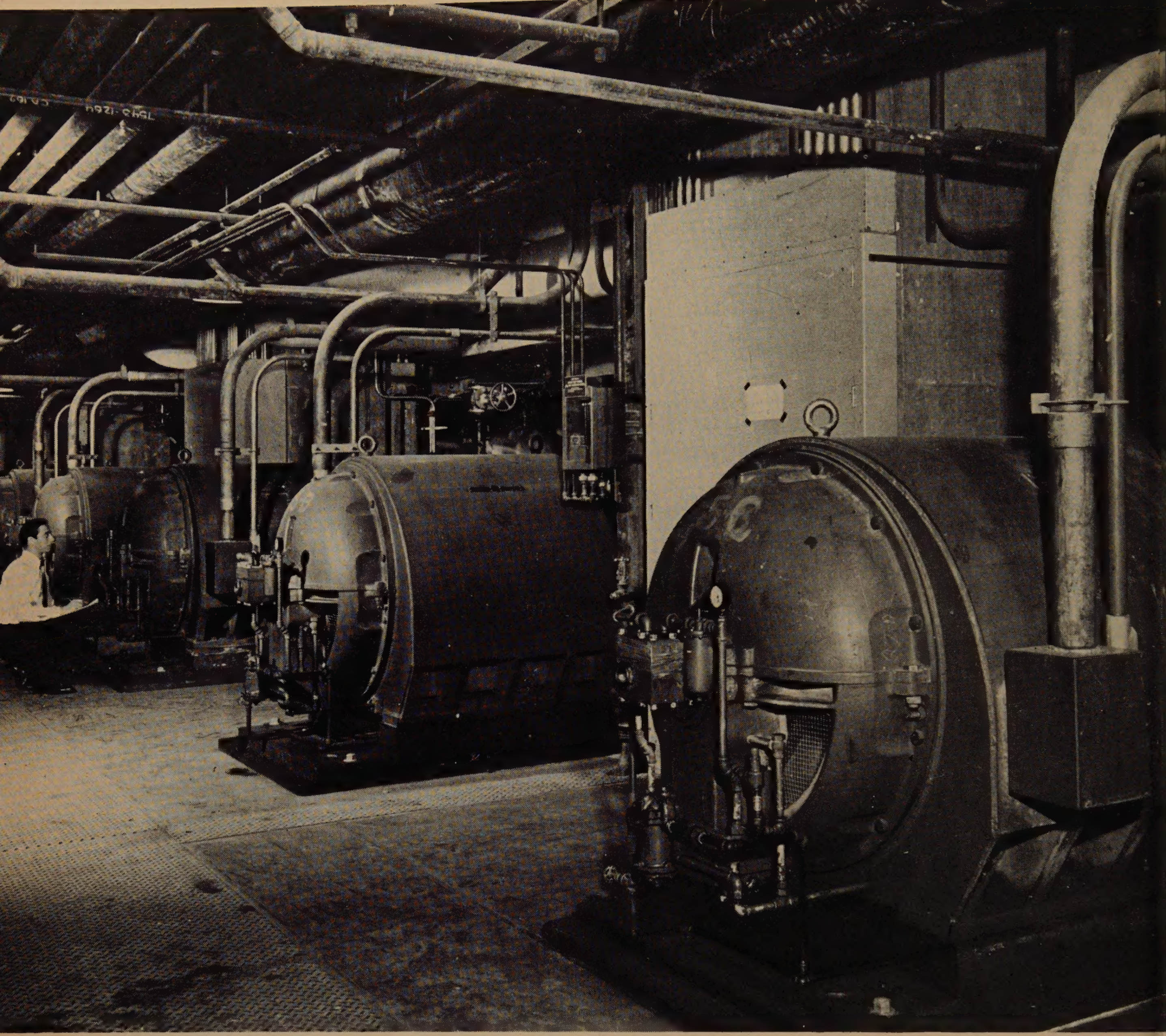

POWER FOR PUMPS

**Six of nine 1000-hp motors installed to drive boiler-feed pumps in a new pl
extension supplying power to Los Angeles. The full-load rating of e
of the motors is 1000 hp, 215 amp, 2300 volts, 3 phase, 60 cy
at 3580 rpm. Each drives a double-case boiler-feed pu
rated 850 gallons per minute at 3410 ft dynamic h**

FLAMMABILITY MEASUREMENTS ON THIN SHEET MATERIALS AND FABRICS

Flammability of material in these forms is sometimes a matter of life or death. New tester reveals in one simple operation the factors involved in combustion of certain textile, rubber, paper, or plastics materials

James R Blegen

By JAMES R. BLEGEN
Alkyd Products Engineering Division, Chemical Department
General Electric Company

ONE frequently reads in the newspapers of the serious injury or death of persons when articles of wearing apparel have been transformed into envelopes of flame due to accidental contact with open flames or radiant heaters. Holocausts such as the Boston Coconut Grove fire and the Ringling Brothers tent fire—wherein decorative and functional fabrics caught fire bringing sudden death to hundreds of people—made even more shocking reading in the not-too-distant past.

EARLY ATTEMPTS AT TESTING FLAMMABLE MATERIALS

Aroused by the deaths and serious injuries arising from flammability accidents, the State of California was moved to action and passed the Flammable Fabrics Act in 1946. This Act pertained only to materials for wearing apparel. The items with which the fire marshal was primarily concerned were the shaggy, brushed rayons, such as had been involved in cowboy-suit accidents; lightweight pyroxylin-coated fabrics used as raincoat materials; and net fabrics. A number of such materials have figured in flammability accidents over a period of years and have a comparatively high accident-frequency rate. In addition to these items, comparative evaluations were desired on other fabrics and on the then rather novel plastic film, but the fire marshal was somewhat handicapped for a satisfactory impartial test procedure.

Since that time California has extended the flammability legislation to cover other items such as drapes, drops, decorative materials, and the like, used in places of public gathering. Some other states have considered action along similar lines, and bills for federal legislation have been introduced into Congress from time to time. In each instance, one of the major deterrents to writing suitable legislation has been the lack of suitable testing equipment and substantiated limiting values.

TEST METHODS INVESTIGATED

A textile trade association, feeling that there was a growing need for removing hazardous materials from the market, had set up a committee in 1943 to investigate test methods for flammability and to attempt to arrive at a limiting value of what should be allowable for commercial use. It was partly around the findings of this committee and partly around the fire marshal's own investigations that California patterned its flammability legislation.

At first, those few persons in the fledgling plastics film industry who had given flammability any consideration were lulled into a false sense of security because tests made on plastics film in the accepted textile industry tester indicated that the plastic film did not burn—and indeed it did not, by that method of test. A simple match test—that is, igniting a piece of plastic film with a match—indicated that some of these films burned fairly readily; consequently data sometimes at variance with both tests were received by firms submitting samples to California. Because there was so much confusion surrounding the status of plastic material with regard to flammability, a committee, with the writer as chairman, was assigned by the Society of the Plastics Industry* to investigate the matter.

For some months following the formation of this committee, many standing methods for evaluating flammability were studied. The method for textiles was not directly adaptable to plastic films because under conditions of that method even nonflame-retarded plastic film did not burn. Knowing that this was not a true indication, work was done on modifying this test procedure. One modification was found to produce results analogous to those obtained by the California test method, but since this also was not considered satisfactory, such a method was not deemed worthy of proposing as a standard procedure. Considered inadequate, also, were the ASTM and Bureau of Standards test procedures, those used by other governmental agencies, and several other methods used by private concerns.

Concurrently, it was considered necessary to establish what relationship arbitrary test methods had to actual burning of a material in service. Tests were conducted on vertically suspended samples, two feet long by one foot wide, and on aprons fitted on a clothing dummy. In this investigation tests were made on a wide assortment of textile fabrics, varying from lightweight chiffons and sheer rayons through heavy broadcloth, percale, and jersey. Also tested were vinyl films, polyethylene and Pliofilm materials; oil, pyroxylin, and

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This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

*The General Electric Company is a member of this Society.

rubber-coated fabrics; rubber sheet; and paper. Colored motion pictures were taken showing the burning behavior of the materials from the time a flame was applied until the fire had extinguished itself. A large clock and a large rule were so placed in the camera range that the factors of time and intensity of flaming could be judged accurately.

EXPERIMENTAL TESTER A NECESSITY

From these motion-picture data and from laboratory experimental data obtained by testing in various manners on arbitrary testing equipment, an attempt was made to draw some tentative conclusions. The classified results indicated that it not only would be advantageous but practically a necessity to construct a better tester for evaluating the hazards of materials in combustion. Following this, a very crude experimental flammability test model was built which, it was hoped, embodied principles that would provide a true measure of the relative hazards involved in combustion.

The objective was to provide a tester which would be applicable to unsupported thin plastic films; heavy-gage unsupported plastic materials; fabric supported plastic materials; textiles of all types; and rubber, paper, and miscellaneous sheet materials of any degree of flammability or flame-retardancy. Guided by the motion-picture studies, it seemed apparent that the unit should measure the ease of ignition; the rate of burning; the intensity of heat; the ease of extinguishment for combustible materials; and the period of after-flame and after-glow for partially combustible materials. Because the crude model tester had shown great promise, an experimental commercial model was constructed from funds supplied by the Society of the Plastics Industry. This experimental commercial model has now been on test in various laboratories for a year and a half. Minor technical modifications to simplify operation have been made from time to time.

THE TESTER AND ITS COMPONENTS

Essentially, the tester is composed of a steel cabinet 11 in. by 12 in. by 15 in. high, the interior of which is nickel plated to prevent excessive rusting from corrosive fumes, and two specimen holders made of nickel-plated steel. The cabinet serves as a draft shield and as a mount for the 45-deg rack and vertical holder, for flame jets, a monometer, a pyrometer and an instrument panel which contains operating switches and timing clocks. The cabinet is vented, has a hinged glass-faced door at the front, and an opening on the right side where the 45-deg specimen holder is inserted. The instrument with a combustible test sample in the 45-deg position is shown in FIG. 1 together with one of the technicians who operate it.

The specimen holder for 45-deg testing is made of ⅛-in. steel, nickel-plated, and is essentially in the form of a large open U-spring clamp. The upper and lower plates of the U-shaped holder fit snugly together and are held thus by a spring hinge at one end and a spring-locking device at the other end. The upper and lower plates hold the specimen in position between them leaving an open center portion 1.5 in. wide by 8 in. long where the burning takes place. A white sample can be seen thus positioned in FIG. 1. The specimen holder has a 45-deg bend in it, one inch from the lower end, such that when the holder is positioned as in the photograph, the lower end of the holder and that portion of the specimen are in a vertical position. There are two microswitch-actuating springs located on the specimen holder. The springs are held under tension and from contact with the microswitches by No. 50 heavy, or heavy-duty cotton sewing thread stretched from the springs across the burning area, to the opposite side of the holder. One thread is located just above the 45-deg bend in the holder; the other is at the upper end of the holder. Both threads lie flush on the surface of the sample and allow actuation of the microswitches controlling the clocks when the flames burn through the thread.

The specimen holder itself slides into the cabinet on rails located on a stationary 45-deg mounting rack. The holder is completely removed from the cabinet following a test, and insertion of the samples and tripping threads is done conveniently with the holder outside of the cabinet. Other existing testers have had a stationary sample holder within the cabinet which is inconvenient to work on because of the limited space. One of the most important differences is that other holders have used 0.009 or 0.016 in. wire strung ¼ in. apart to support the sample. It has been proved that these wires conduct heat from the burning sample, greatly retarding the burning rate of thin-gage or sheer materials. Another important difference is that ignition time and intensity of burning are simultaneously obtained, and ease of extinguishment can also be evaluated from one test sample.

TESTING MATERIALS NORMALLY ENCOUNTERED

The operating procedure for testing combustible materials is, first, to locate the threads that hold the actuating springs; then, to insert the sample into the holder. The holder containing the sample is placed on the rails of the rack through the opening at the right side of the cabinet and is allowed to slide by gravity into position. A ½-in. flame from a No. 22 hypodermic needle, controlled by a needle valve and judged by gas pressure on the monometer, impinges on the surface of the lower vertical section of the specimen when the holder slides into operating position. At that instant the holder actuates a microswitch which starts the left-hand clock shown in the photograph.

With the first burst of flame from the sample, the lower trip thread burns through, actuating another microswitch which stops the clock. This registers the time of ignition. Simultaneous with the stopping of the left-hand clock, the right-hand clock starts and remains running until the sample has burned a 6-in. distance. At that instant the upper trip thread burns through, stopping the right-hand clock which registers the time of burning. Thus, both time of ignition and rate of burning are automatically obtained without any judgment on the part of the operator, and the values are held until the clocks are cleared. The clocks are graduated in tenths of a second, and one complete revolution of the hand denotes 10 seconds.

While this operation is proceeding automatically, an iron-constantan thermocouple located about one inch above the sample surface, near the upper end of the sample, is registering the heat of the flame on the pyrometer. When the second clock has stopped, the operator may, if he desires, quickly remove the specimen holder containing the still flaming specimen and try to extinguish it. The holder has a laminated phenolic handle which does not become unduly warm, and the approximate ease of extinguishment can be judged by fanning the holder in the air. Some materials extinguish immediately; others burn all the more furiously. Actual tests have shown that the entire loading, burning, and unloading cycle can be accomplished in less than one minute for common fabrics.

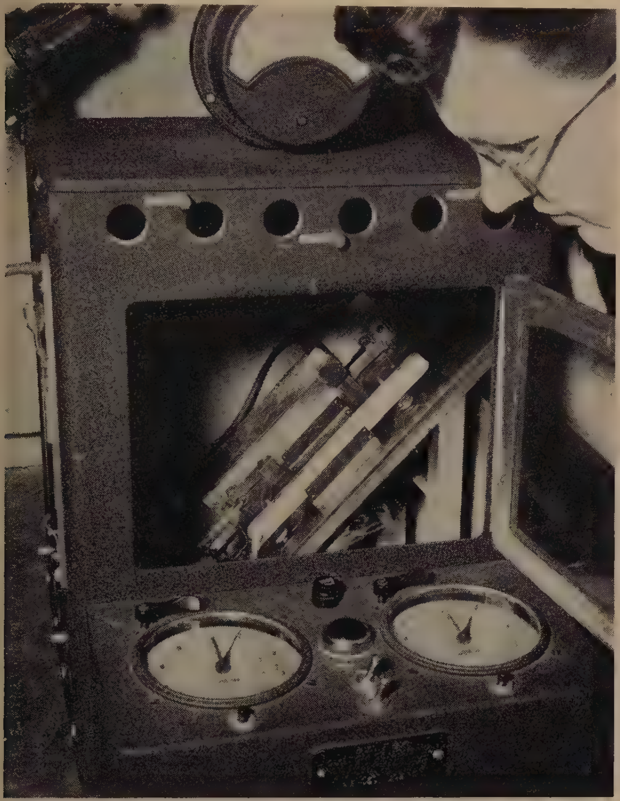

Fig. 1. The testing instrument is shown with a sample placed in the specimen holder on the mounting rack. The clocks register time of ignition (*left*) and time of burning (*right*)

Readily combustible materials vary in ignition time from 0.1 sec to several seconds, whereas burning rates vary from under 2 sec up to 40 or 50 sec, depending upon the material. Values for a relatively homogeneous material are very reproducible. Pyrometer readings vary from 100 F up to 800 F, although obviously the amount of fuel (thickness of sample) must be taken into account. Samples from less than 0.001 in. up to 0.250 in. are readily accommodated with no adjustment necessary. The holder is so designed that regardless of differences in thickness of samples, the distance from the igniting flame remains the same.

TESTING MATERIALS HAVING ABNORMAL BEHAVIOR

Thus far only testing of the normally encountered combustible materials has been mentioned. Some materials, notably certain plastics, are extremely difficult to ignite but, once ignited, burn fairly readily. Such materials will not take fire by the test just described, but it would be misleading to say that they are not flammable. In such instances, a 1.5-in. flame from a microburner located in the base of the tester is brought into action by turning a valve on the tester. Such samples are tested with both this flame and the hypodermic jet flame playing on the vertical section of the sample.

Still other materials are so highly flame-retarded that they will not support combustion once the flame has been removed from the sample. When such materials are tested a vertical holder is used, and a flame from 1.5 to 5 in. long is played on the sample from the microburner for a prolonged period. This holder hangs in the center of the cabinet on a shaft grooved to automatically fall into position when inserted in the fourth vent hole from the left at the top of the cabinet. This holder fits between the rails of the stationary rack; and, of course, the 45-deg holder is removed during such tests. A small pilot flame operates continuously, but when a valve is turned the flame assumes full-test size.

After the holder and sample have been swung into position by means of a knob on the suspending shaft, this valve is turned, allowing the flame to assume a predetermined size. The flame is held for a specified period (about 10 or 12 sec), then the valve is turned to Off (to pilot light only) and the period of after-flame and the period of after-glow are noted on the clocks. For such tests, manual operation of the clocks is necessary. This is done by throwing the toggle switches from automatic to manual operation, and using the push-button switches located at the front of each clock.

Materials of differing degrees of flame-retardance have to be categorized and then tested in their respective groups. For materials whose behavior is completely unknown, increasingly severe tests must be run until one which is severe enough to produce results is reached. This is necessary for an extremely wide range of materials for the same reasons that one would measure one gram of material on a laboratory balance and ten tons on a suitable high-capacity scale. Common household fabrics can be tested by the 45- deg automatic test. Only for highly flame-retarded materials used in a few specific applications are the other test procedures required. A number of plastic materials are entering into the latter categories, however, because of incorporation of flame-retarding materials into them.

Although the flammability tester can be operated on city gas, or a variety of bottled gases, work has been standardized utilizing CP butane as the fuel. This

(Concluded on following page)

Gluttons for Punishment

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FLAMMABILITY MEASUREMENTS

(Continued from preceding page)

eliminates variation in results due to different Btu contents of fuels. Butane gives a considerably hotter flame than city gas and hence produces a more rigorous test.

RESULTS OBTAINED BY THE TESTER

Results from various laboratories where the tester has been on trial have shown that reproducible results can be readily obtained by different operators in different laboratories. Comparisons made by several companies between this and other flammability testers have shown results to be far more reproducible on the tester described than on the others. It has further been shown by comparing data obtained from this tester with motion-picture data of large-scale burning operations that results are of the same relative order of magnitude for a wide range of materials. Testers employing wire-strung sample holders have been shown to be in large error due to differential retardation of burning rate by the wires. Heavy samples on such testers are relatively slightly retarded, while very thin samples are greatly retarded in burning.

So far as is known, there is no other tester in existence capable of evaluating with so simple operating procedures the various factors concerned in combustibility on such a wide range of materials by predominantly automatic means.

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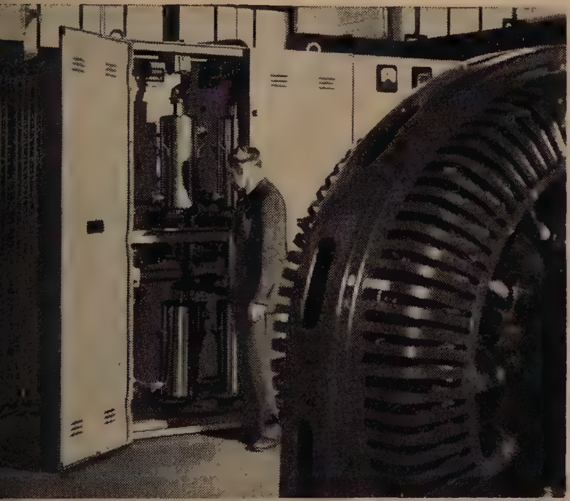
he 500-kw, 250-volt G-E rectifier at the Florence Pipe oundry and Machine Company requires only periodic nspection.



he G-E rectifier provides the d-c power which operates e cranes, ladles, and centrifugal casting machinery the Florence Company's plant.

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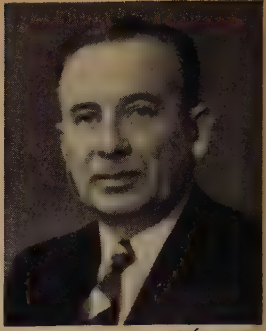
GENERAL ELECTRIC

687-33

MERCURY-CYCLE POWER GENERATION

A progress report of mercury-unit power plants commercially used for production of electric power and primary steam, covering principally the last decade of operation; developments that have led to overcoming almost insurmountable obstacles; and resultant benefits responsible for the highly successful operation of today's mercury-steam power plants



Harold N. Hackett

By HAROLD N. HACKETT
Construction Engineering Division, Apparatus Department
General Electric Company

THE mercury-steam power cycle for a given initial temperature is the most efficient electric-power-generating cycle in commercial use today. A 40,000-kw mercury-unit power plant placed in service in late 1949 is expected to produce electric power at an over-all thermal efficiency of over 37 percent. Standard-design mercury-unit power plants planned for future installations may be designed to operate at thermal efficiencies in excess of 40 percent when burning either Bunker "C" fuel oil or pulverized West Virginia coals.

The mercury-steam power plants operating in the United States have definitely established the economics of the mercury cycle as a reliable method for producing low-cost electric power and steam.

Electric energy produced in public-utility generating stations by the mercury-steam power cycle in the United States has exceeded 5.3 billion kilowatt-hours. Approximately 2.63 billion of these kilowatt-hours were generated directly by mercury-vapor-driven generators and the remainder from the by-product high-pressure steam by associated steam-turbine units. This total of 5.3 billion kilowatt-hours of electric energy was produced, in the operating plants, at a heat rate in Btu per net kilowatt-hour considerably below that of the power systems' next most efficient power-generating unit. An additional 576 million kilowatt-hours of electrical energy and 11 billion pounds of 400-psig steam was generated for industrial uses by the 20,000-kw mercury-steam power plant located within the Schenectady (New York) Works of the General Electric Company.

Had this very appreciable quantity of electric power been generated by means of conventional steam-generating units of like vintage, the nation's fuel resources would have been depleted by more than one billion pounds of equivalent coal over that which was actually required to produce this power by mercury. Such enormous savings in fuel merely indicates the magnitude of future savings of world fuel resources that may be expected by the extensive use of this highly efficient power-generating cycle.

STATUS OF EXISTING MERCURY POWER PLANTS

The status—general operating and design information, as of 1949, covering the mercury power plants in operation or planned for operation—is given in Table I.

HARTFORD ELECTRIC LIGHT COMPANY

The original 10,000-kw mercury plant installed in 1928 in the South Meadow Station of the Hartford Electric Light Company at Hartford (Connecticut) was taken out of service in the summer of 1947 for complete dismantling to provide space for a new unit of modern design and 50 percent larger capacity.

The original unit, built entirely of carbon-steel parts, operated more than 119,000 hr during the 19 years between 1928 and 1947, and produced in excess of 1.7 billion kilowatt-hours of electric energy from the combined mercury-steam output of the unit. This unit was the first commercial application of the mercury-steam cycle for superposition of existing steam-generating units, although an earlier plant of only 1800-kw capacity had been operated experimentally at the Dutch Point Station of the same company.

The attractive economic value of the mercury-steam cycle for producing low-cost electric power and steam, plus the very evident obsolescence of the original 10,000-kw mercury equipment, caused the Hartford Electric Light Company to purchase and install a new replacement unit (FIG. 1) having a maximum continuous rated output of 15,000-kw and approximately 200,000 lb per hr of either 250-psig, 700-FTT* steam or 385-psig, 700-FTT steam.(1)

The new equipment began preliminary operation January 2, 1949, and was declared in service February 1, 1949, as firm generating capacity at base load in the South Meadow Station.

The operation of the unit to date has been most satisfactory with a minimum of plant operation trouble. For the period from February 1, 1949 to May 31, 1949, the mercury plant operated 2510 hr at an average load on the mercury-turbine-generator of 13,900 kw and at an availability of 87 percent.

20,000-KW MERCURY POWER PLANT, KEARNY

The 20,000-kw mercury plant (FIG. 2) located in the Kearny Generating Station of the Public Service Elec-

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This article was presented as a paper at the Fourth World Power Conference, July 1950, London (England).

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

*FTT signifies degrees F total temperature.—ED.
(1) Numbered references are listed at the end of the article.

TABLE I

GENERAL PLANT AND DESIGN-PERFORMANCE DATA FOR MERCURY POWER PLANTS

(Compiled as of June 1, 1949)

	Hartford Electric Light Company South Meadow Station		Public Service Electric & Gas Company Kearny Generating Station	General Electric Company, Schenectady Works Mercury Steam Station	Public Service Company of New Hampshire, Schiller Station	General Electric Company, Pittsfield Works Power Station
	10,000 kw Original Unit	15,000 kw New Unit				
GENERAL PLANT DATA:						
Location of the mercury plant	Hartford (Conn.)		South Kearny (N.J.)	Schenectady (N. Y.)	Portsmouth (N.H.)	Pittsfield (Mass.)
Mercury power-plant rating, kilowatts	10,000	15,000	20,000	20,000	40,000	7500
Steam output, pounds per hour	124,000	210,000	290,000	325,000	0	124,500
Mercury-turbine throttle conditions, $_p$, F	85_p, 883 F	130_p, 947 F	140_p, 958 F	140_p, 958 F	128_p, 944 F	128_p, 944 F
Steam conditions, superheater outlet, $_p$, FTT	400_p, 700 FTT	400_p, 700 FTT	380_p, 750 FTT	415_p, 750 FTT	615_p, 825 FTT	640_p, 825 FTT
Types of applications	Central station		Central station	Industrial	Central station	Industrial
Types of service	Base load		Base load	Mfg. load	System load	Mfg. load
Types of fuel burned	Fuel oil		Pulv. coal and fuel oil	Pulv. coal	Pulv. coal and fuel oil	Pulv. coal and fuel oil
Date mercury plant placed service	1928	1949	1933	1933	1949	1949
Percent availability of mercury plant as of June 1, 1949	85	87	73	52		
Present status of mercury plants	Dismantled 1947	Operating	Operating	Dismantled 1949	Under construction	Under construction
MERCURY-PLANT DESIGN-PERFORMANCE DATA:						
Mercury boiler-drum outlet conditions	100_p, 907 F	145_p, 964 F	155_p, 975 F	155_p, 975 F	143_p, 962 F	143_p, 962 F
Mercury-turbine throttle conditions	85_p, 883 F	130_p, 947 F	140_p, 958 F	140_p, 958 F	128_p, 944 F	128_p, 944 F
Quality of mercury vapor	Dry and saturated	Dry, saturated	Dry, saturated	Dry, saturated	Dry, saturated	Dry, saturated
Mercury-turbine exhaust conditions, $_p$, F	1.38_p, 478 F	1.5_p, 485 F	1.3_p, 475 F	1.23_p, 471 F	2.53_p, 528 F	2.80_p, 530 F
Mercury-turbine throttle flow, pounds per hour each	1,080,000	1,640,000	2,200,000	2,143,000	987,000	987,000
Number of mercury turbines per plant	1	1	1	1	2	1
Number of mercury boilers per plant	1	1	1	1	2	1
Design maximum rated output of mercury turbine generators, kilowatts	10,000	15,000	20,000	20,000	17,060 (8530 each)	8400
Quantity of steam produced by mercury plants pounds per hour	124,000	210,000	300,000	325,000	248,700 (for two)	124,500
Steam-turbine throttle conditions, $_p$, FTT	400_p, 700 FTT	400_p, 700 FTT	380_p, 750 FTT	Steam piped to factory for process and other uses	615_p, 825 FTT	640_p, 825 FTT
Steam-turbine-generator output kilowatts	E 12,400	E 19,100	E 25,000		D 26,400	Steam piped to existing station steam header
Total combined plant generation, kilowatts	E 22,400	E 34,100	E 45,000		D 43,460	
Mercury-plant auxiliary requirements, kilowatts (includes steam turbine auxiliaries where required)	600	900	2000	1750	Coal 1940 Fuel oil 1515	900
Mercury-plant combined net output, kilowatts	21,800	33,200	43,000		41,520 41,945	
Mercury-plant fuel requirements, Btu × 10^6 per hour	232.0	334.0	450.0	500.0	391.1 386.0	203.0
Percent average plant load factor	57.3	82.8	86.7	44.2	Under construction	Under construction

LEGEND
D = Design
E = Equivalent
F = Saturated temperature (Fahrenheit)
FTT = Final total temperature after superheating
$_p$ = Pounds per square inch absolute

tric and Gas Company underwent extensive alterations in 1939 in an effort to modernize the plant and to correct certain faults.(1)(2)(3)

The original seven-drum porcupine-tube boiler with its steam-producing water-cooled furnace was replaced with a mercury boiler of more conventional design and of sufficient capacity to operate continuously at guaranteed output. Only the boiler was completely replaced and the steam superheater and coal pulverizers required but minor alterations, while the tubular-type air preheater and fans were of ample capacity to serve the new boiler.

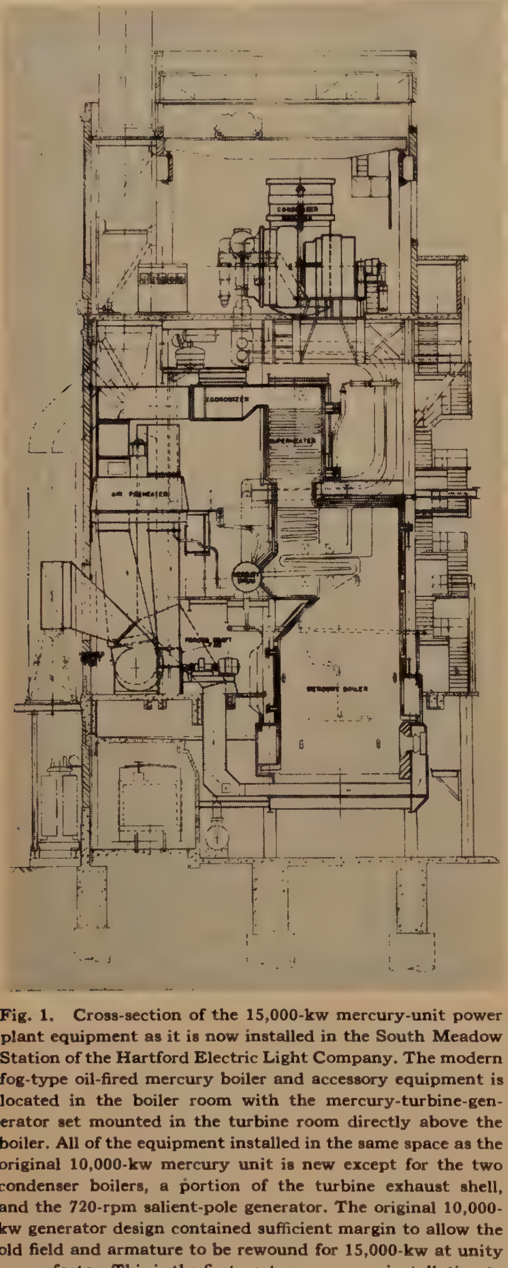


Fig. 1. Cross-section of the 15,000-kw mercury-unit power plant equipment as it is now installed in the South Meadow Station of the Hartford Electric Light Company. The modern fog-type oil-fired mercury boiler and accessory equipment is located in the boiler room with the mercury-turbine-generator set mounted in the turbine room directly above the boiler. All of the equipment installed in the same space as the original 10,000-kw mercury unit is new except for the two condenser boilers, a portion of the turbine exhaust shell, and the 720-rpm salient-pole generator. The original 10,000-kw generator design contained sufficient margin to allow the old field and armature to be rewound for 15,000-kw at unity power factor. This is the first postwar mercury installation to be placed in operation

The remodeled plant was placed in operation again in June 1940 as firm capacity on the Public Service and Gas Company's power system and has produced a gross total of more than 2.18 billion kilowatt-hours of electric energy at an average load factor of 86.7 percent and an average availability of 72.7 percent.

All of the original carbon-steel mercury-turbine valves and vapor pipes and boiler relief valves, after some 82,000 hr of operation at 975 F are being replaced this year with new parts built of moly-vanadium steel. During the same outage the 900-rpm 5-stage double-flow mercury turbine will be opened for inspection and repairs. The machine has not undergone internal inspection since it was reconditioned ten years ago in 1939, and so it is expected that some replacement of worn parts will be required, particularly in the low-pressure portion of the turbine.

The mercury boiler also is scheduled for complete inspection at the same time, and all necessary repairs will be made to place the unit back in first-class condition again. Certain of the lower- or first-pass fog-convection tubes in the hotter portion of the boiler are to be converted into up-flow rather than down-flow circuits to improve their circulation characteristics and reduce their tendency for over-heating and starvation under adverse coal-ash slagging conditions.

The existing eight inner-tube-type combination pulverized-coal or fuel-oil burners are to be replaced by six circular-type turbulent burners mounted on only six of the eight side walls of the octagonal furnace. It is expected that these new burners will considerably improve the furnace conditions by shortening the flame travel, thereby producing more uniform heat distribution within the furnace.

The ten years' operation of the present mercury boiler has produced a gradual wearing away of the alloy-steel tube metal on the fire side of the tubes. This loss of metal is the result of soot blower and fly-ash erosion and metal oxidations under normal operating conditions encountered with pulverized coal or Bunker "C" fuel oil. Approximately eight and one-half years of the boiler's operation have been with the unit burning pulverized bituminous West Virginia coals and the remainder of the time burning Bunker "C" fuel oils of commercial quality.

In 1948 and again in 1949 the thinned sections of certain of the floor tubes were reinforced with an almost impervious oxidation and erosion-resistant coating of 25 (chromium)—20 (nickel) arc-weld deposit. This material has successfully withstood the damaging effects of ash-and-flame erosion, as well as oxidation, at the elevated operating temperature of the tubes. Metallurgical examination of pieces of 25-20 pad-welded floor tubes showed the base metal and the 25-20 weld deposit to be in excellent condition.

The specimens examined had been in operation approximately nine months with no indication whatever of intergranular failures between the welded-on pad and the chrome-alloy tube material. Based upon these encouraging findings, some 2500 linear feet of furnace floor tubing was repaired during the winter of 1948, and an additional 14,000 linear feet will be pad-welded with 25-20 weld material during the plant overhaul in 1950.

0,000-KW MERCURY-STEAM PLANT, GENERAL ELECTRIC OMPANY, SCHENECTADY WORKS

The 20,000-kw mercury-steam power plant that is ocated in the Schenectady Works of the General Electric Company(4) was taken out of service in 1948 ecause of equipment obsolescence and metal fatigue f certain of the high-temperature-mercury pressure arts. Unusually frequent service outages caused by hese failures made it advisable to discontinue operaion of this unit until such time that new equipment of nodern design is installed.

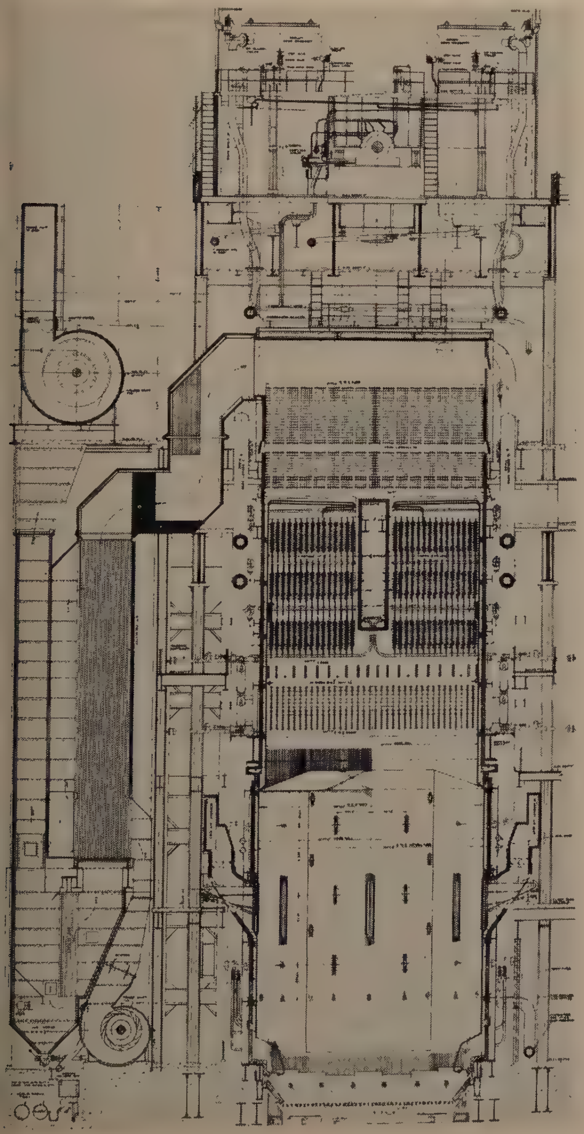
During the greater part of its useful life, this plant operated as an experimental unit, and as such suffered many changes and design alterations. Because of the war, and for other reasons, the plant was not modernized to a sufficient degree to permit continuous and eliable operation. Studies are being made as to necesary alterations or changes that may be made to make he most satisfactory power-generating unit for suplying the Schenectady Works power and steam equirements.

During the fifteen years that the Schenectady mercury plant operated, it generated more than 576 million kilowatt-hours of electrical energy from the mercury-turbine-generator and approximately 11 billion pounds of 400-psig, 750-FTT steam for process and manufacturing uses. Even though the average load factor was only 44 percent and the availability 52 percent, the experimental and operational data gained from this plant has made the installation worthwhile.

THE SCHILLER STATION OF THE PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE

The new 40,000-kw Schiller Station of the Public Service Company of New Hampshire (FIG. 3) located upon a new site at Portsmouth (New Hampshire) is the first application of a complete mercury-unit power plant for the purpose of generating electric power only. The Schiller Station is the first mercury-unit power plant of its type, having been sold as a complete power-generating unit, designed and built by the General Electric Company upon the purchaser's foundations.

The entire building, including the building mat, equipment foundations, and circulating-water tunnels, was designed by the General Electric Company. However, the building mat, equipment foundations, and the circulating water tunnels were constructed and supplied by the Utility Company while the remainder of the



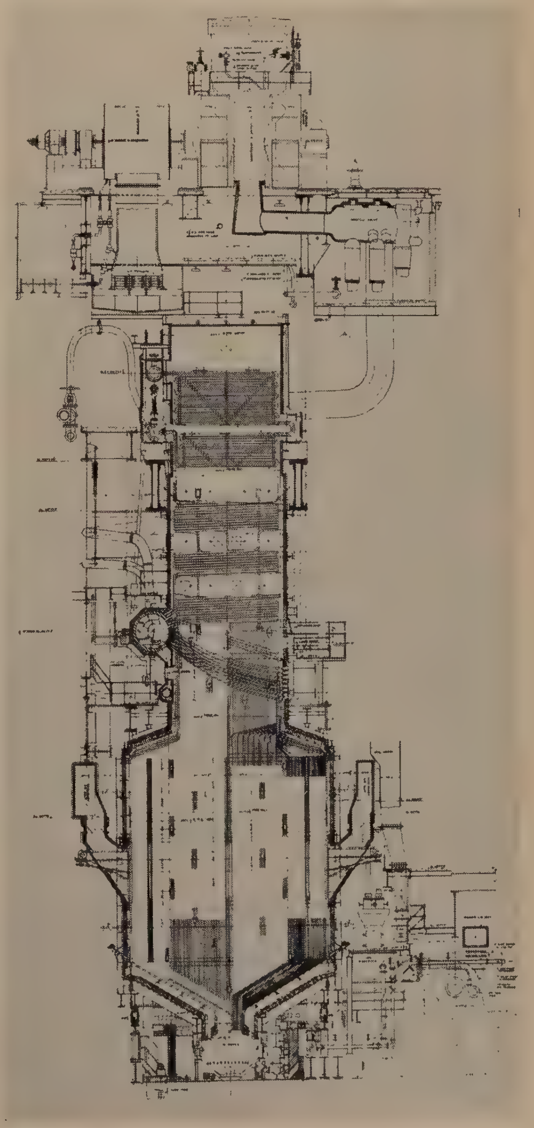


Fig. 2.
Two cross-section views of the 20,000-kw mercury plant in the Kearny Generating Station of the Public Service Electric and Gas Company. The large single-drum mercury boiler is the first all-alloy fog-type unit to be installed, having replaced the original seven-drum porcupine-tube-type boiler installed in 1933. The new boiler was placed in service in 1940 and with the associated mercury-turbine and steam-turbine equipment has produced more than 2.18 billion kilowatt-hours of electrical energy

Fig. 3. The new 40,000-kw mercury-cycle Schiller Station of the Public Service Company of New Hampshire. This highly efficient ultramodern station is the first application of a complete mercury-unit power plant in America. Two standard-design 7500-kw mercury-unit power plants are co-ordinated in arrangement to supply 600 psig 825 FTT steam to a 25,000-kw steam-turbine set, giving a designed generating capacity of 40,000 kw. The mercury boilers are designed to burn either pulverized coal or Bunker "C" fuel oil

plant—the building proper; all equipment, whether mechanical or electrical; all piping; and the stack, coal, and ash-handling units within the confines of the power plant—was furnished, erected, and made ready to operate by General Electric.

As a complete plant—as in a machine—the over-all input and output is guaranteed as though the plant were a motor or turbine alone. The over-all plant heat rate of 9420 Btu* per net kw-hr when burning 13,500-Btu per lb West Virginia bituminous coal makes this the most efficient 40,000-kw electric-power-generating unit in America. When the plant is burning Bunker "C" fuel oil, the guaranteed net heat rate is 9200 Btu per net kw-hr.

The mercury power plant as now designed and constructed includes certain facilities required for future plant extensions, because it was more economical to include these provisions with the first unit rather than later. The coal yard, coal-conveying, and docking equipment is ample for the full development of the plant. The condensing-water intake and discharge tunnels are ample for the next extension as is the cable-duct system running from the station to the out-of-doors switch yard. Likewise, construction offices and storage buildings provided for the first unit are readily usable for the next addition to the plant. Even though all of these additional items will be required for the completion of the ultimate plant, they have, of course, materially increased the cost of the initial installation.†

7500-KW MERCURY-UNIT POWER PLANT, GENERAL ELECTRIC COMPANY, PITTSFIELD WORKS

The 7500-kw mercury-unit power plant (Fig. 4) located in the power plant of General Electric Company at Pittsfield (Massachusetts) is an excellent example of how the mercury-steam cycle may be used to produce low-cost power and steam for industrial uses. The new standard-design equipment is located in a remodeled portion of the old power house and is designed to produce 8400 kw of electric power and 124,500 lb per hr of 640-psig, 825-FTT steam at maximum rating. The steam thus produced is piped to the 640-psig station steam header for use as required by existing condensing-extraction steam-turbine units, which prior to the installation of the new mercury plant were the only source of power generation in the Pittsfield Works.

Additional condensing-extraction steam-turbine capacity could not be added in the Pittsfield Works power plant because of an extreme shortage of condensing water. Although an additional steam boiler could have been added to firm up the factory steam supply, the increasing electrical power requirements offered further problems due to a definite deficiency in generating capacity in the Pittsfield area.

Final studies indicated that a 7500-kw mercury-unit power plant could be installed about as rapidly as the increased loads would materialize. Although the initial investment in a mercury plant was somewhat higher than for the other schemes studied, the expected net return on the total investment appeared to be sufficiently attractive to choose this way of adding capacity. The mercury plant would have the added advantage of not imposing any increased load on the station condensing-water facilities.

DEVELOPMENTS THAT MADE MERCURY-STEAM CYCLE COMMERCIALLY SUCCESSFUL

A number of very important developments have taken place during the past decade that have contributed immeasurably toward making the mercury-steam cycle commercially successful. Each of these new developments has either directly or indirectly improved the reliability of the mercury power-plant equipment or made lower-cost high-efficiency designs possible.

CHEMICAL TREATMENT OF MERCURY

Probably the most important development thus far made in the art of mercury power generation was the discovery of suitable and reliable treatment of the boiler mercury.(2) This important work under the supervision of A. J. Nerad, Research Laboratory, General Electric Company, made possible the establishment of predictable and controllable wetting of the inside surfaces of the mercury furnace and the mercury-boiler convection tubes.(2) Nerad found that a dilute amalgam of magnesium and titanium metals, dissolved in the boiler mercury, completely changed the functioning of the mercury within the mercury boiler tubes.

The "wetted" surfaces thus produced were found to be capable of absorbing heat at almost unbelievably high rates as long as the wetting action was maintained.

Furthermore, laboratory and field tests indicated that the metal wastage on the inside surfaces of the boiler tubes caused by the dissolving of the iron in the hot mercury would be substantially or entirely eliminated. These discoveries gave promise of removing the two serious, apparently insurmountable obstacles in the path of mercury-steam-cycle development.

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*Btu heat values wherever used in this article have been based upon the "higher" or "as fired" calorific heat content of the fuel.

†For a complete description of this station, see the article, "The New Schiller Station: Complete Mercury Unit Power Plant," by H. N. Hackett, published in the March 1950 issue of the Review.—Ed.

Operating experience gained in the existing mercury power plants indicates that heat-transfer failures due to nonwetting and the wastage of the internal tube surfaces due to solubility of the tube material in mercury have been entirely eliminated. As final and complete proof of these successes, microscopic examination of the inner surfaces of tubes removed from the Kearny mercury boiler after ten years of service shows them to be in the same condition as when installed, except for a thin protective film of titanium-iron compound that had been formed on the wetted surface.

OXYGEN CONTROL

Correct treatment of the boiler mercury is only possible when and if the oxygen admission into the mercury system is maintained at or near zero. By the use of properly designed all-welded mercury pressure and vacuum parts, the use of packless leak-proof valves, nonleakable centrifugal mercury-type shaft seals, and all-welded construction throughout, oxygen absorption by the mercury has been satisfactorily controlled. Total air leakage of less than one cubic foot per hour is now considered normal in a modern mercury power plant. The use of such inert gases as nitrogen and CO_2 in vessels where the mercury would otherwise be exposed to air has further decreased the possibility of oxygen absorption under normal plant operating conditions.

PROGRESS IN MERCURY-BOILER DESIGN

The benefits resulting from the successful treatment of the boiler mercury are many but none more important than those pertaining to the basic principles of mercury-boiler design. The ability to maintain high heat-transfer rates in all portions of the mercury heat-absorbing surfaces, regardless of the fluid density of the mercury liquid-vapor mixture within the tubes, has completely altered the concepts of mercury-boiler designs.

Nerad found that extremely high heat-transfer coefficients were obtained in boiler tubes having flow mixtures in the order of less than two pounds of mercury liquid to each pound of vapor generated, as long as wetting was properly maintained. However, in the actual design of power boilers, the mercury liquid-vapor ratio is in the order of seven pounds of liquid per pound of vapor for the heaviest loaded circuits with the average for all flow circuits approximately ten to one.

These discoveries made possible the use of simple flow circuits where the mercury coolant entering the tubes at the bottom may flow upward through the furnace portion of the circuit, horizontally in the roof section, downward through the vertical slag-screen elements, and again horizontally through the so-called fog-convection passes to the drum where final separation of the vapor and entrained liquid occurs. Fig. 5 shows such a circuit which, in reality, is a typical front-

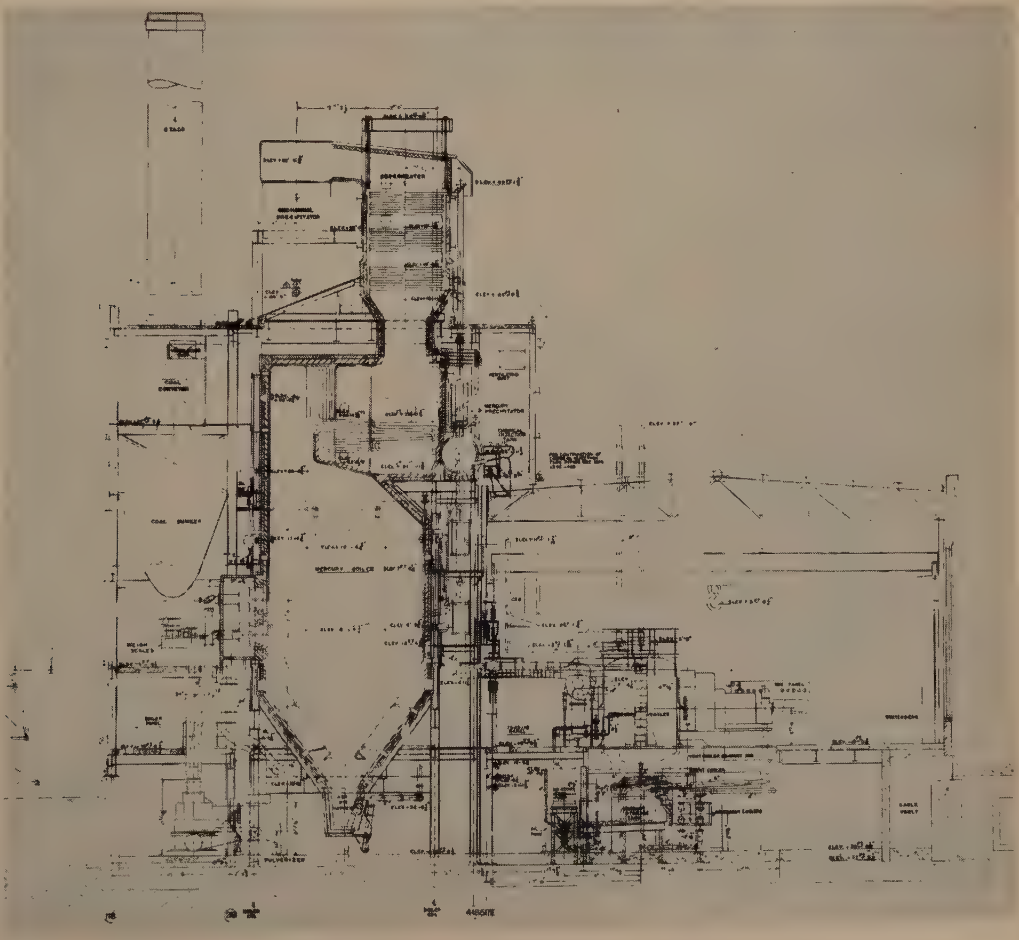


Fig. 4
Cross-section drawing of the 7500-kw mercury-unit power plant installed in the Pittsfield Works Power Station, General Electric Company. The mercury equipment used in this plant is of standard design and rating and will produce electric power and 640 psig 825 FTT steam for manufacturing uses. This unit plant has been in operation since August 1949

wall slag-screen and fog-convection-surface circuit used in the standard design 7500-kw mercury-unit power-plant mercury boilers now operating in the Schiller Station and in the General Electric Company's Pittsfield Works power plant. Circuits of similar design, except for the omitting of the lower sloping end, were used in the 15,000-kw mercury boiler for the Hartford Electric Light Company. FIG. 6 shows a cross-section of the Hartford mercury boiler and FIG. 7 the 7500-kw boiler.

The extensive use of this general type of flow circuit in all modern mercury-boiler designs has produced single-drum boiler units of simple design, requiring a minimum quantity of liquid mercury for operating the unit. The cold, as well as the normal operating level of the mercury, is maintained at or near the inside bottom of the boiler drum thereby leaving the upper several feet of the furnace tubes, the horizontal roof tubes, the down-flow slag-screen tubes, and the horizontal fog-convection passes entirely empty at starting. When the boiler is fired, heat absorbed by the mercury within the furnace tubes produces circulation as a result of the thermal vapor pump formed therein. As the firing rate increases, circulation improves until a definite and positive flow of mercury vapor-liquid mixture is established throughout the entire flow circuit.

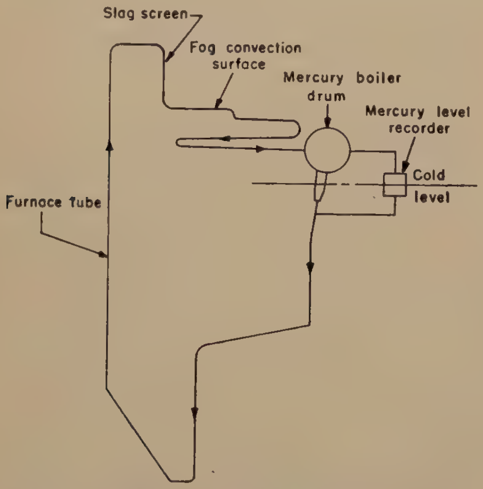


Fig. 5. Diagram of a typical front-wall tube circuit as used in the standard-design 7500-kw mercury boilers that are installed in the 40,000-kw Schiller Station and in the Pittsfield Works Power Station. Similar circuits were used in the 15,000-kw mercury boiler now operating at Hartford, except that the sloping lower portion of the tubes was eliminated to form a flat-bottom-type unit for burning fuel oil only

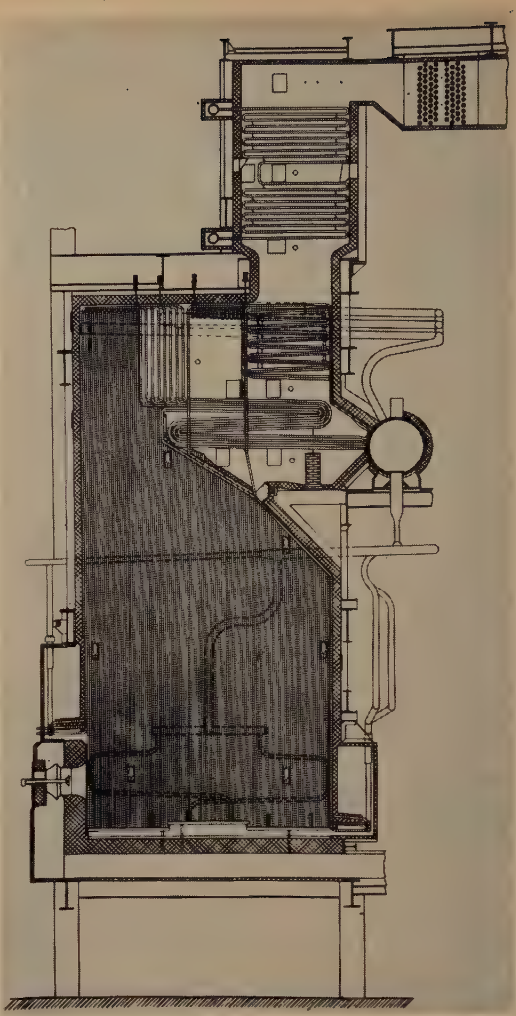


Fig. 6. Cross-section drawing of the new 15,000-kw mercury boiler showing the mercury boiler drum, the mercury liquid downcomer system, and boiler heat-absorbing system. The front- or burner-wall tubes supply coolant to the upper portion of the front wall, the short roof section, the down-flow slag screen and the three-pass horizontal fog-convection tubes before discharging into the vapor-separating drum. Some of the rear-wall tubes continue upward as the support members for the horizontal fog banks, then turn to form the third-pass convection coils, before entering the drum. The remainder of the rear-wall tubes are bent to become a part of the first- and second-pass convection circuits. All of the side-wall tubes attach to their upper vapor headers which in turn are piped to the vapor drum. The 15,000-kw Hartford boiler was manufactured and erected by Foster-Wheeler Corporation of New York

The previously empty upper portion of each flow circuit has now become filled with a high-velocity heat-absorbing fluid having a density of from 30 lb per cu ft to 10 lb per cu ft, depending upon the portion of the circuit under consideration. Uninterrupted and steady circulation is usually attained at or near 25 percent of design full-load flow, thereby establishing the minimum continuous operating rating of the mercury boiler. However, because of the positive wetting ability of the dilute mercury-titanium magnesium amalgam in the boiler tubes, the tube circuits remain at safe operating temperatures at lower heat inputs even though the circulation at this low load may be intermittent and erratic.

A mercury boiler designed upon the simple principles outlined will contain a minimum of mercury, because the only pressure parts that contain mercury at starting are the portion of the furnace tubes below the drum and the downcomer supply pipes and lower headers. The quantity of mercury thus required is only a fraction of what would be used if the boiler drum were mounted in the usual position at the top of the furnace and all the tubes were liquid filled as in the normal steam boiler.

Unlike the condition in the usual steam boiler, cooling for the otherwise empty tubes above the cold level is provided directly from and by the boiling mercury in the furnace tubes. No additional mercury make-up is required as a consequence of the effects of thermal expansion, since direct bloating of the vaporizing mercury in the tubes is sufficient to provide the needed fog mixture.

SPECIAL INSTRUMENTATION FOR MERCURY BOILERS

The development of reliable treatment for the boiler mercury was indeed a long step toward the goal of successful mercury-boiler operation, but that alone did not completely remove all the operational problems that are normally encountered.

To protect the boiler circuits from annoying operating interruptions, a system for measuring and recording the temperature of each boiler furnace tube hourly was developed and the necessary instruments are now included as a part of every mercury-boiler installation.

Under normal operating conditions with treated mercury, the metal temperature of each mercury furnace tube approaches very closely the saturated temperature of the boiling fluid contained therein. The actual relationship between the tube metal temperature and the temperature of the boiling fluid is sufficiently well-known to make possible the design of recording charts and over-temperature alarms for each boiler before the unit is placed in service.

The scanning and recording of all furnace-tube temperatures regularly provides the boiler operator with a continuous record of the thermal condition of the complete boiler unit, including the various slag-screen and fog-convection circuits since they are merely continuations of the front- and rear-wall furnace tubes. This has proved to be an extremely reliable tool for the mercury-power-plant operators as borne out by experience over a period of approximately nine years at Kearny and Schenectady. The boiler-tube scanners have, in every case, indicated, recorded, and alarmed the overheated tubes many hours in advance of an actual or potential tube failure.

MEASUREMENT OF MERCURY-BOILER CIRCULATION

The quantity of mercury circulated in a mercury-boiler-tube circuit, such as used in the modern-design mercury boilers (FIG. 7), may be influenced materially by the rate and manner in which the heat from the fire is applied. Test and operational results have proved that, when heat at relatively high rates, such as those encountered in a dry-ash-type furnace, is absorbed by the upper portion of a mercury furnace tube operating with mercury level depressed as in FIG. 5, the weight of mercury circulated by thermal action may be only 50 percent of what it would have been if the principal heat absorption had occurred in the lower portion of the furnace tube.

By means of suitable furnace design and proper location of the fuel burners, the desired effect of "low" firing can be readily obtained with the result that the mercury circulation can be accurately predicted and be of ample quantity for any given type of fuel or firing conditions. However, should a change in fuel or firing conditions cause abnormal slagging of the furnace tubes, a marked reduction in mercury circulation might be expected, because a slagged-up furnace tube produces the undesirable condition of so-called "high" firing. Extreme cases of slagging, and therefore effective "high" firing, not only reduce the effectiveness of the tube's thermal pumping action and therefore circulation, but also increase the duty required by the fog-cooled convection tubes which under the conditions of the reduced circulation may overheat or fail if operation is thus continued.

The measurement of the boiler circulation by means of necessary flow nozzles and recording instruments properly connected to the main boiler downcomer system provides a record by which the boiler operator may know the circulation conditions within the boiler circuits at all times. By proper interpretation of the circulation readings at any load, it is possible to predict with reliable accuracy when the furnace requires slag cleaning. The operation of the automatically operated air-blow boiler soot and slag blowers may, if thought desirable, be controlled directly from the boiler circulation instrument so that slag accumulations of a serious nature cannot occur.

STANDARDIZATION

The mercury-steam power cycle is inherently a large power-producing cycle because the ratio of mercury

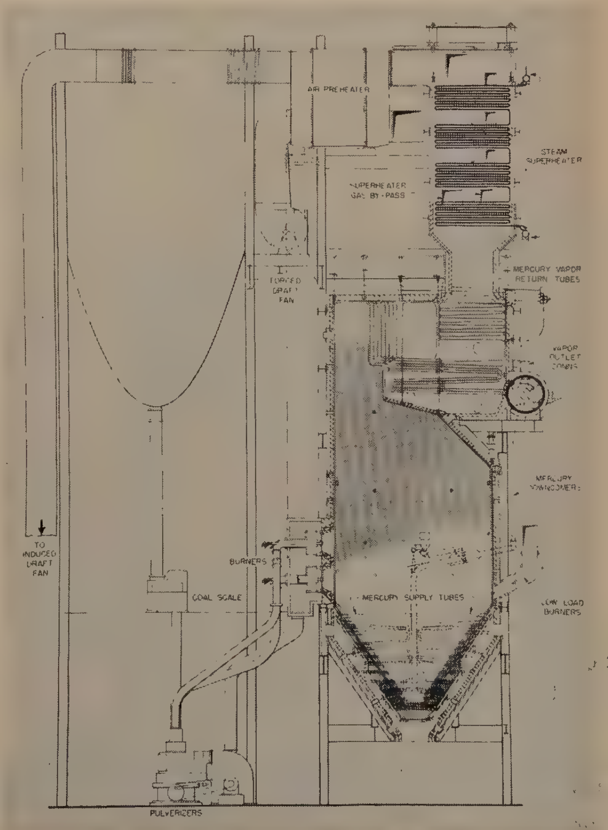


Fig. 7. Section of the standard-design 7500-kw mercury-unit power plant mercury boiler. Two of these units were required in the 40,000-kw Schiller Station and one unit for Pittsfield Works. The three boilers were manufactured and erected from identical drawings by the Babcock & Wilcox Company of New York. This design is typical of mercury-unit boiler designs, being suitable for burning either pulverized coal or fuel oil

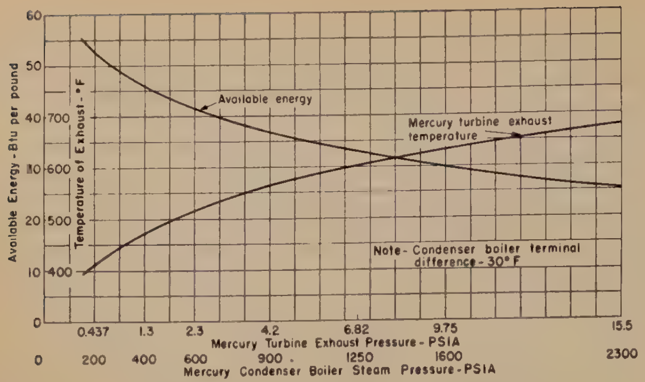


Fig. 8. Plot of the available energy of one pound of mercury vapor when expanding from 140 psia to various exhaust pressures. Mercury-turbine exhaust pressures and mercury exhaust temperatures are shown for various steam-pressure conditions within the condenser boiler steam drum. The change in turbine exhaust temperature of approximately 160 F when producing steam over a pressure range of from 400 psia to 1600 psia is accompanied by a change in available energy of only 16 Btu or 35 percent of the initial value

power to by-product steam produced is a maximum over the entire range of steam pressures normally used in America today. Likewise, the mercury-steam power cycle lends itself admirably to standardization of mercury-equipment design to cover this wide range of steam pressures because of the relatively small change in the mercury-turbine output where producing by-product steam over extremely variable steam-pressure conditions.

These important characteristics are true because of the inherent thermal properties of mercury vapor. When mercury vapor expands in a mercury turbine, there is a large change in the mercury-turbine exhaust pressure, and therefore in the temperature, for a relatively small change in energy used by the turbine. This means that the power produced by a mercury turbine varies only slightly for a relatively large change in its exhaust pressure. Furthermore, it means that steam can be produced from the rejected heat energy in the exhaust vapor over a wide range of pressures with a minimum variation in the mercury-turbine output for any initial mercury-vapor flow conditions.

The pressure and therefore the temperature of the mercury-turbine exhaust, when producing steam in the mercury-condenser boilers, is a function of the saturated steam temperature corrected for the terminal difference between the condensing mercury vapor and the boiling water within the steam generating tubes. In modern-design mercury-condenser boilers, a terminal difference of 30 F is used giving an over-all heat absorption from the condensing vapor to the boiling water of the order of 20,000 Btu per hr per sq ft of tube surface.

Fig. 8 is a plot of the available energy of mercury vapor and the mercury-turbine exhaust temperature when expanding one pound of vapor from the initial conditions of 140 psia 958 F to various exhaust pressures required to produce steam in the condenser boilers.

The change in exhaust temperature of approximately 160 F when producing steam over a pressure range of from 400 psia to 1600 psia is accompanied by a change in available energy of only 16 Btu or 35 percent.

STANDARD-DESIGN MERCURY TURBINES

With this basic information in mind, standard-design mercury turbines have been developed for operation over relatively wide exhaust pressure for producing by-product high-pressure steam. Fig. 9 is a plot of the kilowatt outputs from the standard design 7500-kw and 15,000-kw mercury-turbine-generator sets when operating at design throttle flows and at design initial mercury-vapor pressures and temperatures.

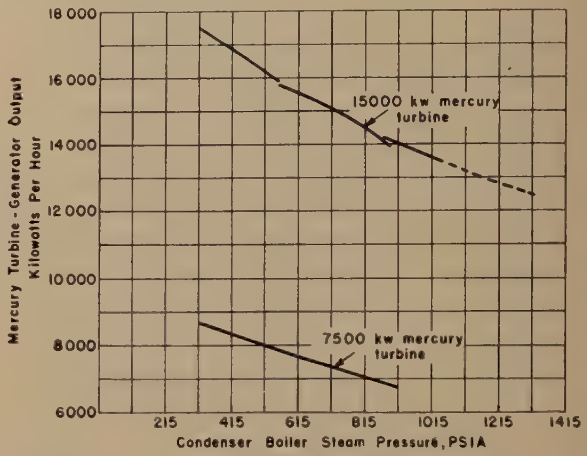


Fig. 9. Plot of the kilowatt output from the standard-design 7500-kw and 15,000-kw mercury-turbine-generator sets operating at design throttle-flow conditions and when producing steam in the condenser boilers at various steam pressures. Here, again, a relatively large change in steam-pressure requirements is accompanied by very nominal variations in the electric power produced by the mercury-turbine-generator

It will be noted that, for the 7500-kw machines, the variation in kilowatt output varies from −10 percent to +15½ percent from nameplate rating kilowatts over a range of steam pressures from 315 psia to 915 psia compared to the variation in output from nameplate rating of 15,000-kw unit which is −16.7 percent to +16.7 percent over the broad steam-pressure range of from 315 psia to 1315 psia.

BY-PRODUCT STEAM PRODUCED

The relatively small change in available energy when mercury vapor expands from an initial turbine-throttle pressure of, for example, 140 psia to the required back pressure for the production of the desired steam also means that the heat rejected to produce this steam is likewise almost constant over the same range of steam pressures. Because of the improvement in machine efficiency as the turbine back pressure increases, there is only about 3 percent to 4 percent change in heat rejected by the turbine for production of from 300 psia to 1300 psia steam.

STANDARD-DESIGN MERCURY CONDENSER BOILERS

This very small difference in heat flow from the mercury turbine exhaust to the mercury condenser boilers is extremely favorable for complete development of standard designs for these units. However, such variables as mercury vapor and steam densities must be corrected for in establishing the original dimensional sizes of the vacuum shell and steam-producing parts. In actual design, condenser-boiler units designed for any given optimum conditions of steam pressure and steam production are satisfactory for a considerable range of pressures above and below the optimum conditions.

The condenser-boiler units (Fig. 10) as now used in the standard line of mercury-unit power plants consist of a centrally placed combination steam-and-water drum to which are attached the steam-generating tubes of proper size and length, all mounted in a vacuum shell as a complete unit.

STANDARD-DESIGN MERCURY BOILERS

The standardization of the mercury-boiler designs offered considerably more complex problems of design because of the variable fuels encountered in general practice throughout the industry. It appeared that the basic boiler designs for a line of standard mercury boilers should be based upon units capable of burning pulverized coal of the various commercial grades with the furnaces designed to operate in the dry-ash condition at all loads.

Mid-Western bituminous coals having a calorific heating value of from 10,000 Btu per lb to 11,000 Btu per lb as received, and containing high percentage of ash having a fusion temperature of from 1900 F to 2000 F, were taken as the fuels upon which the boiler size would be established. In addition, normal boiler full-load rating was then considered to be at the vapor flow which would satisfy the mercury turbine when its generator produced nameplate electrical kilowatts at 0.8 pf at design voltage.

For applications where the fuel to be burned is of superior quality, such as West Virginia or Pennsylvania coals, or Bunker "C" oil or natural gas, the maximum continuous rating of the boiler may then be increased by as much as from 10 percent to 25 percent with resulting improvement in over-all plant output.

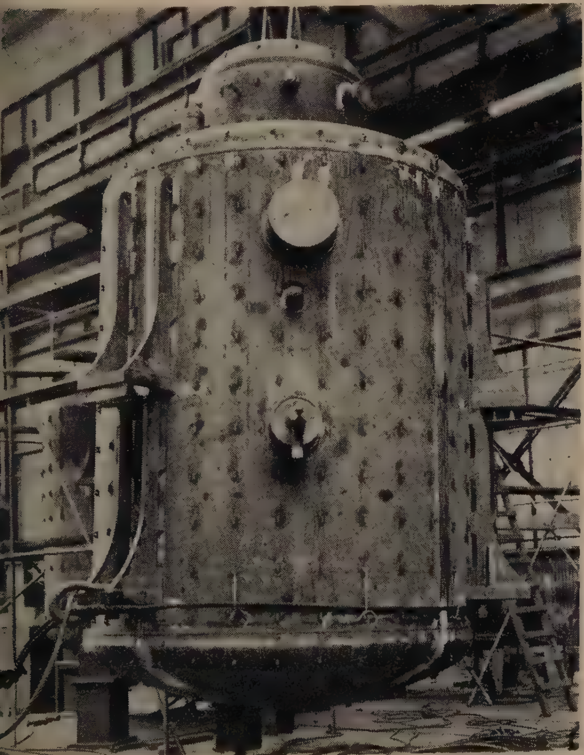
Fig. 7 shows a cross-section view of the standard-design 7500-kw pulverized coal-fired mercury boiler with a dry-ash-type furnace, which is typical of all standard-design boilers. This design is, of course, equally adaptable to fuel oil or natural-gas firing. However, as in the case of the Hartford boiler, the sloping floor tubes may be eliminated and a refractory floor substituted when fuel oil or natural gas are to be the only fuels.

For applications in areas where the lower-grade coals are to be burned, the 2500-kw to 7500-kw boilers may be equipped with spreader stokers (Fig. 11) by eliminating the inclined floor tubes to provide space for the stoker parts. When this type of fuel-burning equipment is used, a considerable reduction in the boiler-plant costs is expected, principally because of the savings in mercury liquid and alloy boiler materials, as well as the use of lower foundations and less costly fuel and ash equipment.

Standardization of mercury-boiler design has also made possible considerable savings in manufacturing costs per boiler, partial shop prefabrication of parts, and uniformity of manufacturing procedures.

STANDARD MERCURY-UNIT POWER PLANTS

One important result of the successful standardization of mercury-equipment designs has been the development of complete mercury-unit power plants of standard design and ratings. These standard plants are designed for use as topping plants where electrical



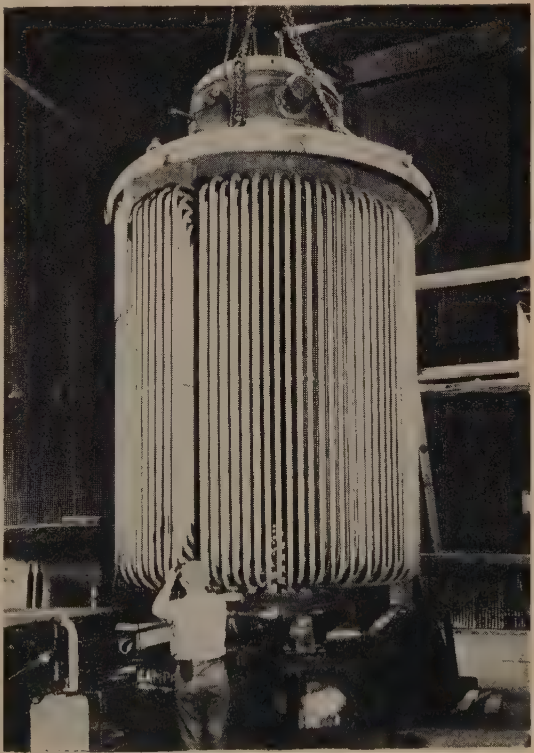


Fig. 10
Two views of one of the standard-design 7500-kw mercury-condenser boilers being assembled ready for shipment to the Schiller Station where four such units are required, two for each 7500-kw mercury turbine. Two identical units were manufactured for the Pittsfield Works installation. The completed assemblies, weighing 80,000 lb each, were readily handled at their respective sites at a minimum of erection time and expense

power and high-pressure steam are required, or as producers of lower-pressure process or heating steam and electrical power for industrial uses, and as complete generating plants where electrical power only is required, as is the case in the usual Power Company applications. The 40,000-kw Schiller Station is an excellent example of such an installation.

The basic designs of these standard plants have been established for what appears to be optimum conditions of steam pressure and temperature, plant ratings, and plant dimensions in an effort to produce units of reasonable cost and acceptable efficiencies. Each unit plant in its capacity range can be altered to further improve the over-all efficiency by the use of higher steam and mercury conditions but at an added cost per kilowatt of capacity. However, as the plants are now designed, the over-all net efficiencies compare very favorably with the best steam-generating plants of largest capacities. For example, when the plant is burning coal, the 9420 Btu per net kilowatt hour for the 40,000-kw Schiller Station is approximately 2000 Btu lower than can be obtained from a modern 850-psig 900-FTT nonreheat 40,000-kw coal-fired steam-generating plant.

EVALUATION OF IMPROVED PLANT EFFICIENCY

These very real savings, which in many cases are more than 2000 Btu per kilowatt-hr of electrical output generated, are ever more important as fuel and other operating costs continue to rise. Fuel costing upwards of 37¢ per million Btu as delivered to the power plants is not uncommon in many sections of America today and, when used in a mercury-unit power plant at fuel reduction of 2000 Btu per kilowatt-hr or more, the value of the fuel savings in dollars per kilowatt of capacity per year (FIG. 12) at 80 percent use factor would be in the order of $5.70. This saving capitalized at 10 percent per year represents a potential capital value of the mercury power-plant kilowatts to be approximately $57 per kilowatt greater than for a steam plant designed for the same capacity and service.

In such a case as this, it is easy to justify the installation of the mercury plant. Cost experience to date indicates that even though the mercury-steam power plant is more costly than a comparable steam plant, the increased efficiency of the mercury-steam plant will, in many cases, warrant the additional investment.

CONCLUSION

The mercury-steam power cycle is the most efficient present means for generating power from fuel combustion. With more moderate temperatures and in smaller sizes, it now closely equals the best in large steam-power practice. Its establishment as an accepted source of firm generating capacity has been brought about by the successful development of a reliable treatment of the

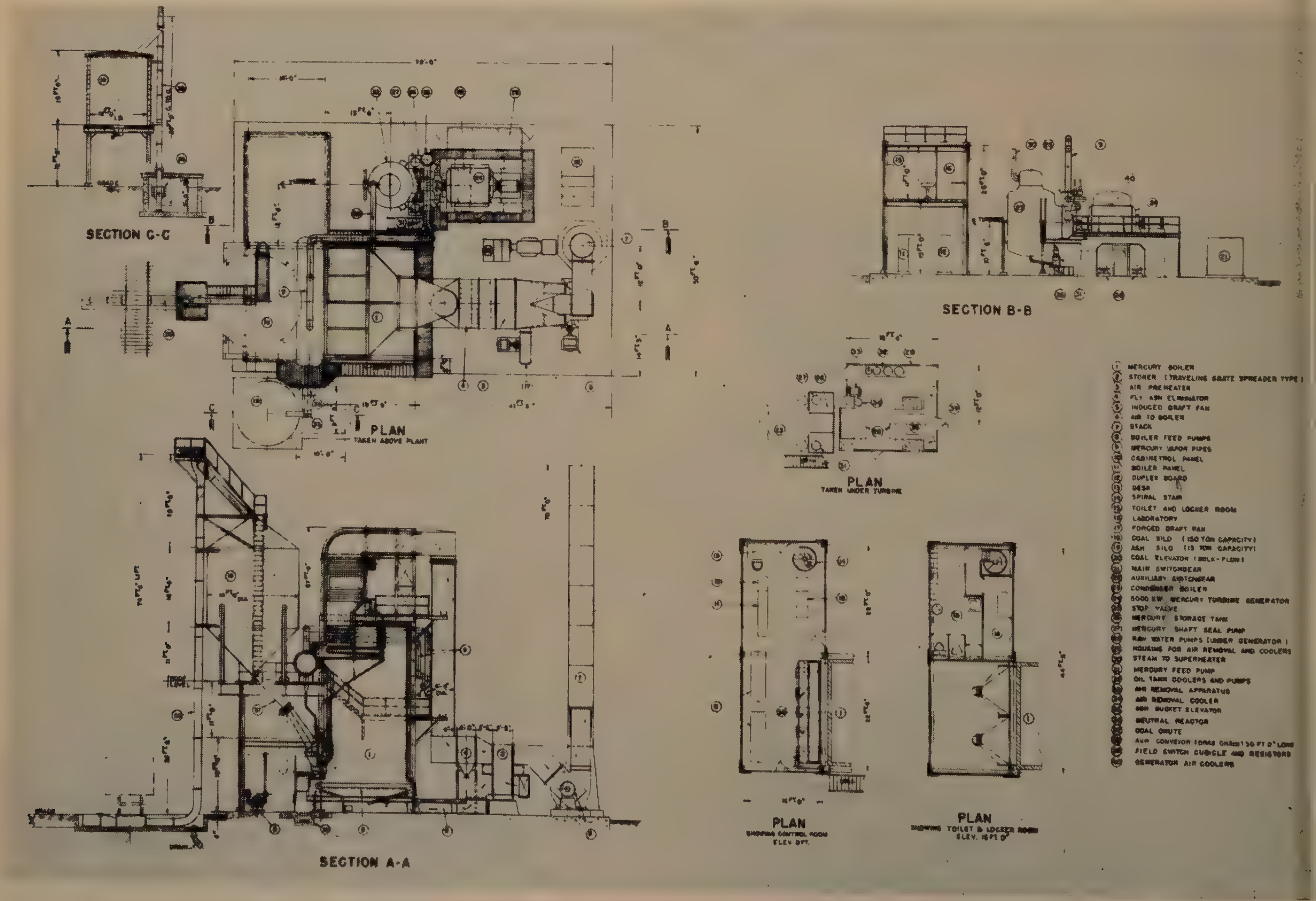


Fig. 11. Plan and section drawing of the proposed standard-design mercury-unit power plant equipped with spreader-type stokers for burning low-grade coals

boiler mercury which has assured the continuous maintenance of adequate heat transfer within the tubes of the mercury boiler. This simple treatment has likewise made possible the use of conventional-design fog-type mercury boilers requiring the minimum of mercury liquid as coolant.

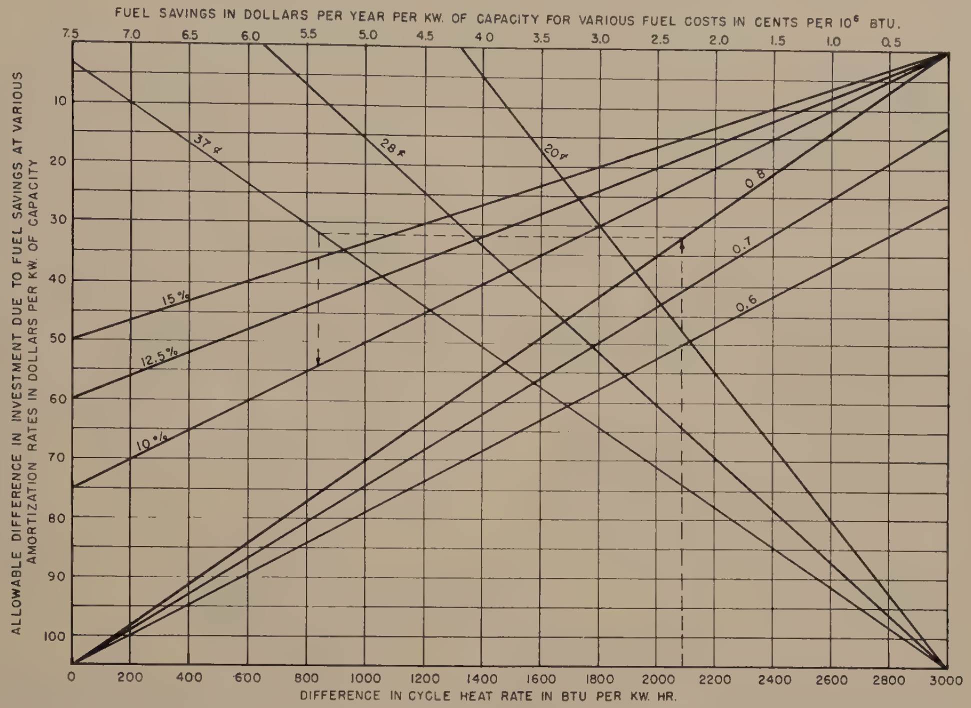


Fig. 12. Plot of evaluation curves where savings in dollars per year or additional value per kilowatt of capacity is plotted for various fuel costs versus fuel savings in Btu per kilowatt-hour

Standardization of mercury equipment, and therefore standardization of the mercury-unit power plant as well, has been made possible because of the inherent thermal characteristics of the mercury itself. The relatively fixed ratio of mercury-turbine kilowatts to by-product steam produced has given the designer a golden opportunity to develop to the fullest extent the standardization of power plants and power-plant equipment over a wide range of capacities.

The economic advantage resulting from such standardization may, of course, be considerable because of the expected savings in over-all power-plant costs. The lower cost per unit of equipment made possible because of the reduction in drafting and engineering expense, minimum supervision and overhead costs per unit, combined with the lower manufacturing and erection costs of producing and erecting the standardized equipment should be considerable. Furthermore, economics in the actual plant design and construction should aid materially in producing a line of standard mercury-unit power plants of high efficiency and reasonable cost.

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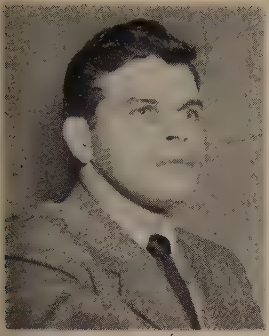

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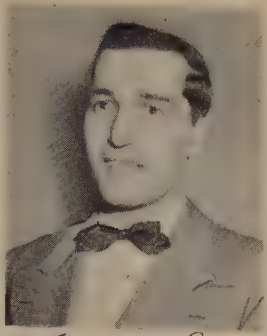

Edwin S. Lawrence

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By
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ONLY during the past ten or twenty years has it become possible to attain sound, serviceable units through the engineering of cast shapes. Before this period, castings were produced under limitations imposed by lack of information about the physical and metallurgical changes in the materials involved; without this knowledge, both designer and foundryman were handicapped. However, the establishment of such data has since made it possible for the foundry, like other metal processors, to engineer its product.

In this field, as in others, engineering falls into the design category and the production class. When foundry engineering is applied to both design and manufacture, sound cast shapes are produced. Its application to one without the other, however, produces sound shapes only a fraction of the time.

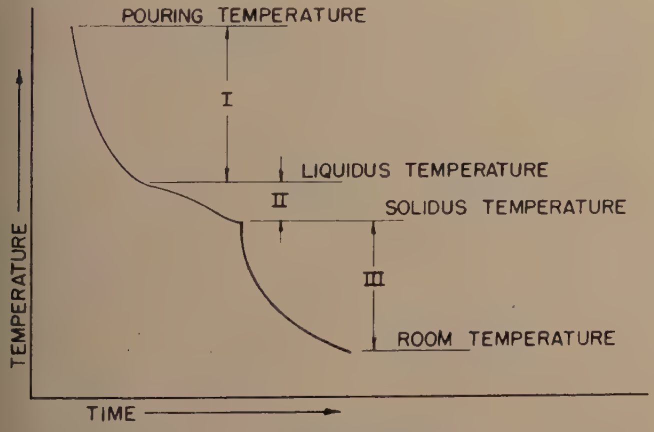

Fig. 1. Typical time vs. temperature cooling curve for a metal

FUNDAMENTALS

Basic research into the various changes which take place during the solidification of a metal from the liquid to the solid state has changed the foundry process during the past decade from a mysterious craft into a highly technical science. From this research, fundamental principles of controlled feeding or directional solidification have been developed. If they are followed, the result will always be a casting free of shrinkage defects.

It was found that when a metal cools from the liquid to the solid states, it undergoes three distinct changes in volume—that is, three shrinkage contractions. This is illustrated in FIG. 1.

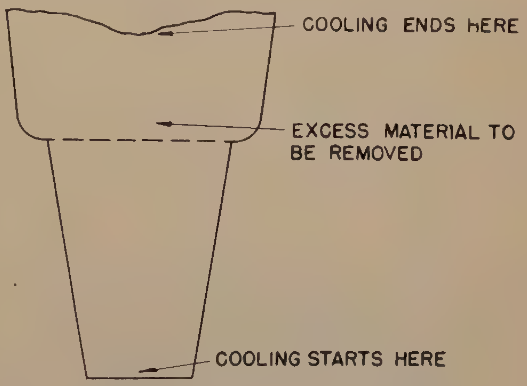

Fig. 2. Progression of cooling in a casting

In cooling from the pouring temperature to the liquidus temperature (Range I), the liquid shrinkage contraction is encountered. In cooling from the liquidus temperature to the solidus temperature (Range II), the metal undergoes solidification shrinkage. The final, solid shrinkage occurs during cooling from solidus temperature to room temperature (Range III). The volumetric contractions in Ranges I and III have been measured by many investigators; their data are the basis upon which patterns are made oversize to produce castings of the correct dimensions.

The all-important shrinkage during the change of state from liquid to solid, however, has been studied only recently. This contraction has been found to be the undisputed source of all shrinkage defects in cast materials; only through its control can internally sound castings be produced. The cooling of the metal during this highly important phase-change must progress from a point at one extremity of the casting section to a final point which is outside of the section and in a part of the casting that may be removed later (FIG. 2).

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If cooling is started (or its directional progress interrupted) at any point within the section, a shrinkage void will result (FIG. 3).

One of the means by which controlled solidification may be insured is through the application of molding materials which possess the desired heat-transfer properties. As shown in FIG. 4, certain materials may be used to extract heat from the molten metal, according to their own abilities to transfer heat. This bronze octagonal section was cast in a mold having a different material for five of the eight faces. The mold was filled and allowed to cool for five minutes; the remaining liquid metal was then bled off. Since the greatest thickness of solid metal is adjacent to the steel face, it is evident that heat extraction took place most rapidly through the steel. The lack of any solid metal opposite the plaster face indicates that the plaster extracted little heat and therefore served as an insulator.

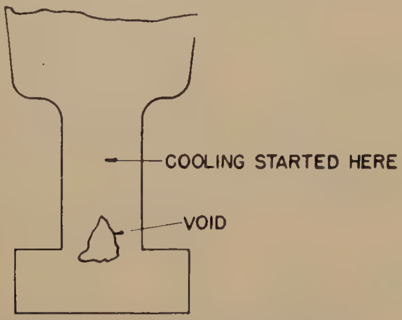


Fig. 3. Formation of a shrinkage void

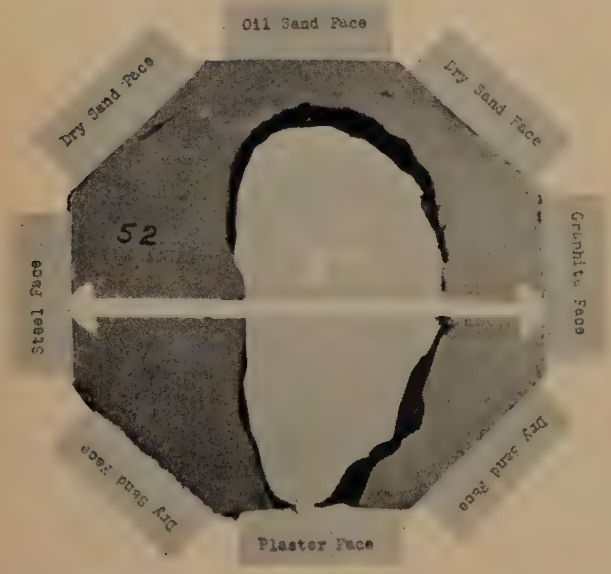


Fig. 4. Arrangement of various surface materials for controlled cooling of a bronze casting to show effects in production-solidifying of material

It is through the use of materials such as those which form the mold used in the demonstration casting that the foundryman is able to control the transfer of heat from light and heavy sections and so produce a sound casting (FIG. 5).

Much of the presently available data on heat transfer in sand molds is only qualitative, since three modes of heat transfer (conduction, convection, and radiation) are involved. However, quantitative information is rapidly becoming available through the use of the differential analyzer and similar machines to calculate the highly complex differential equations involved.

The lack of quantitative knowledge is not a serious drawback except on economic grounds. It is a certainty that if extremes of heat transfer are provided so that directional solidification principles are fulfilled, shrink-free castings will result. Quantitative data will serve only to modify these extreme conditions and so reduce the cost of manufacture.

It has always been regarded that the use of reservoirs of metal was a necessity for soundness. Until the principles of directional solidification were understood, however, the prime function of the reservoir or "riser" was never very clear. It was believed, purely from observation, that the casting sections were fed or made solid by the weight of the metal in the riser exerting a ferro-static pressure upon the metal in the casting below. This observation was only partially correct. It applies only so long as the metal in the section is liquid; as soon as solid crystals or dendrites start to form, it is impossible to force liquid metal through them unless the ultimate strength of the material at that temperature is exceeded. Thus, if the riser is designed with only the ferro-static pressure principle in mind, it will feed metal only in Range I (FIG. 1). It will not provide liquid metal for Range II unless it is designed on the basis that it must be the last point in the section to solidify. To fulfill this requirement, the riser must contain a large volume of metal; in many cases the weight of the casting will be smaller than the weight of the riser, and the cost will be slightly increased. This increased cost, however, will be over-balanced by the fact that freedom from shrinkage is assured, which is the ultimate goal.

New techniques for achieving the same result at a lower cost are rapidly becoming available to the

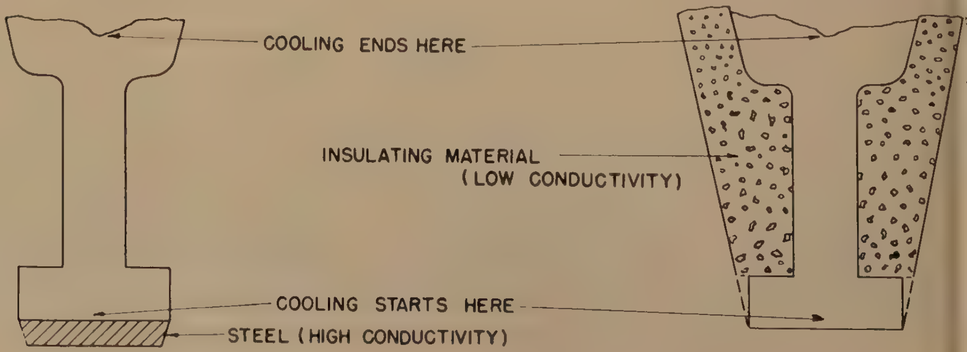

COOLING ENDS HERE
INSULATING MATERIAL (LOW CONDUCTIVITY)
COOLING STARTS HERE
STEEL (HIGH CONDUCTIVITY)

Fig. 5. Application of materials of high and low heat conductivity to control metal solidification

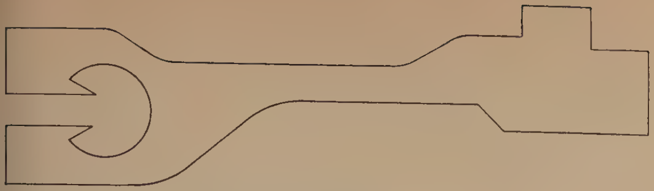
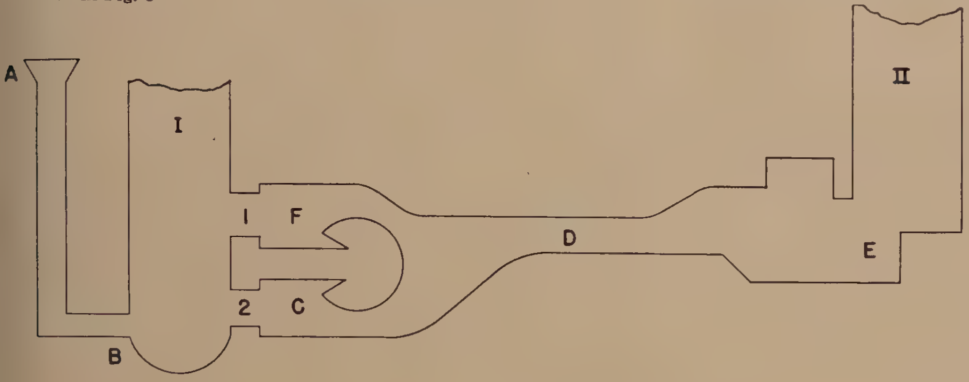


Fig. 6. Cross section of an aluminum casting to which controlled casting methods may be applied

Fig. 7. Original arrangement of risers and gates for casting the section shown in Fig. 6



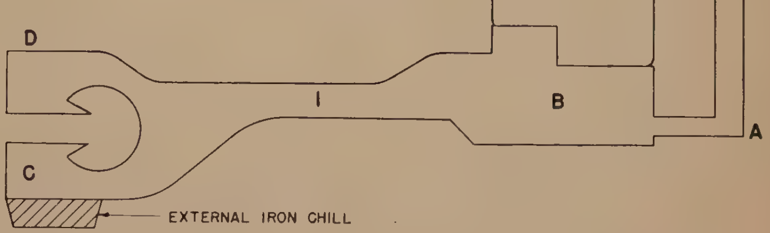


Fig. 8. Corrected arrangement of gates and risers for casting the section shown in Fig. 6

foundry. These include low-conductivity materials to insulate the risers, exothermic compounds which may be added to the risers after pouring, and, perhaps the newest of all, the maintenance of an electric arc in the riser to keep the metal liquid long after the remainder of the section has solidified. All of these techniques are now in use and are serving daily to control solidification as well as to reduce costs.

It has been shown how, through the application of the principles of heat transfer, the section is fed progressively. At this point, the method by which the mold is filled will be considered.

PROCESS

One of the attributes of the casting process is its versatility in the production of various shapes. Most cast units are far too complicated to be filled directly with metal; that is, the metal cannot be poured into an open mold. Therefore, it is necessary to provide separate channels and passages through which the metal may flow into the mold cavity. These are known as "gates."

Like the risers, the gates of a casting must be located according to the principles of directional solidification. Unless the metal be introduced according to these principles, effective cooling rates cannot be established. Since the last metal to enter the mold is the hottest metal, it is of prime importance that it flow into a eservoir or into a section which is assured a supply of eed metal.

Despite the claims which have been made and the countless castings which have been produced in violation of these fundamentals, it can be safely stated that the good castings produced were usually the exception rather than the rule. For example, consider a circular aluminum casting, the cross-section of which is illustrated in Fig. 6. These castings range in size from 10 to 48 in. outside diameter.

Castings were originally produced in molds provided with risers and gates as shown in Fig. 7. When the molten metal was poured into the mold, its path was as follows: entering the mold at point *A*, it passed into riser *I* at point *B*. The metal then continued to fill the mold, covering points *C*, *D*, and *E* and finally filling the entire cavity, including Riser II.

Cooling now proceeds; Riser II will contain the coldest metal in the casting because of the distance the metal has traveled from *A* to *E*. If this reservoir is of extremely large volume, the mass may or may not keep this metal molten. This is the first violation of the principles of directional cooling, and has created a possibility of voids occurring at point *E*. Though metal has been introduced from *A* into Riser I in accordance with the basic principle, a further violation has occurred at point *C*. Riser I will remain molten, but the points at which it joins the section, *1* and *2*, are of small mass (or thin-sectioned). Consequently, these thin sections may solidify long before Riser I and hence make this riser useless.

The possibility of internal voids occurring at points *E*, *C*, and *F* has been shown in the procedure just described. The production record of these castings substantiates this possibility; the rejection rate due to defects in these areas averaged 30 percent.

A reconsideration of the location of the gates and riser produced the arrangement shown in Fig. 8.

The metal now enters the mold at *A* and flows to *B* and finally to *C*. The metal at *C* is the coldest, since heat has been removed from it during its travel through

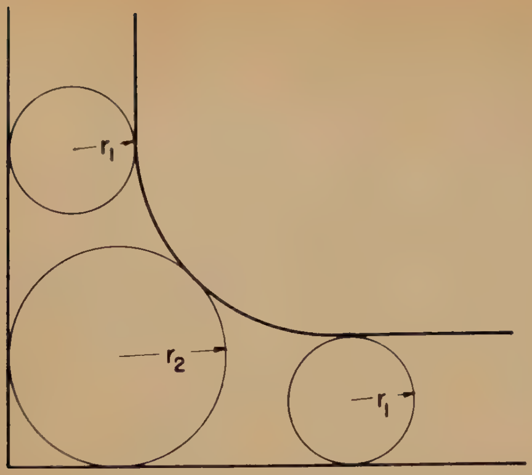


Fig. 9. Inscribed-circle method of determining location of "hot-spots"

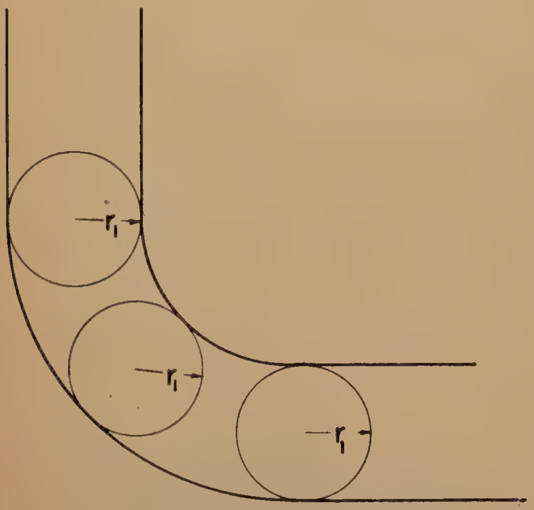


Fig. 10. Redesign of section shown in Fig. 9 to eliminate "hot-spots"

the mold. To insure that cooling will start at point *C* and progress toward *A*, an external, high-heat-conductivity chill is provided. When the thin section at *1* begins to cool, there is a demand for more liquid metal. Riser I supplies this demand as well as that at point *B*, since it has received the last metal to enter the mold and is of large volume. The production record now shows an average rejection rate of 2 percent, with point *D* responsible for the remaining rejections. The design of the pattern prevented the use of a chill at *D*; with either a chill or riser at this point, soundness could be assured.

Although it is now possible for the foundryman to predict defects before they occur, he is often limited, by faulty design, in the application of the directional-feeding principles. It must be clearly understood that the techniques for the production of sound castings can be used only when casting shape has been developed with directional-feeding principles in mind.

DESIGNING THE ENGINEERED CASTING

The foundryman should be a consulting member of the design team. Actually, in a number of cases, he first becomes acquainted with his problem upon receiving the blueprint or pattern and the promised delivery date. The first official consultation may occur only after serious problems have developed during the machining of the casting.

It is difficult indeed to estimate the losses of money and time that have been caused by the lack of complete understanding and mutual appreciation of foundry problems. Certainly a considerable amount of this loss can be attributed to failure to seek the foundryman's aid at earlier stages of design.

Elimination of all shrinkage defects is the major problem confronting the foundryman. Proper casting design is a factor of great importance in the solution of this problem; because of the increased demand made upon the casting and the more rigorous inspection which it must pass, the foundryman can no longer accept for production a poorly designed part. In order that the techniques described may be fully realized, design of the cast section should be such that solidification or crystallization proceeds, step by step, toward the feed-metal reservoirs, so that the demand made by the casting for molten metal is continuously supplied.

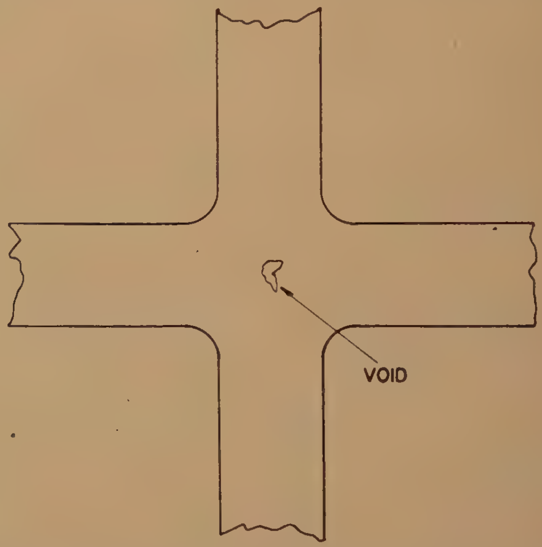


Fig. 11. A section that is troublesome in regard to formation of voids

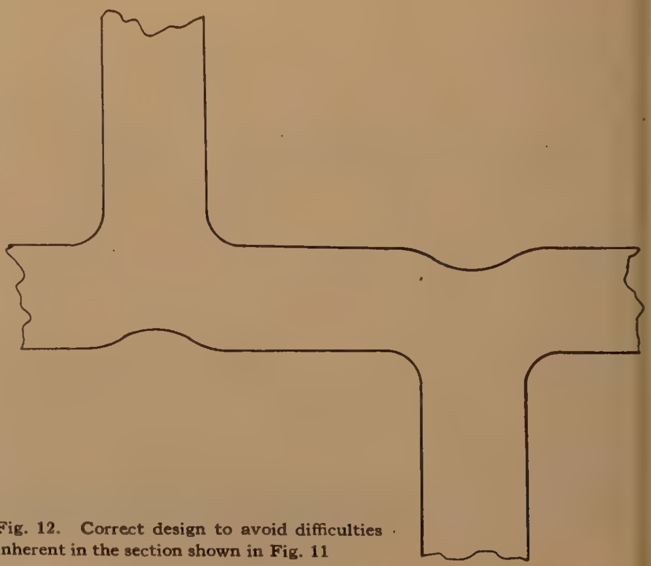


Fig. 12. Correct design to avoid difficulties inherent in the section shown in Fig. 11

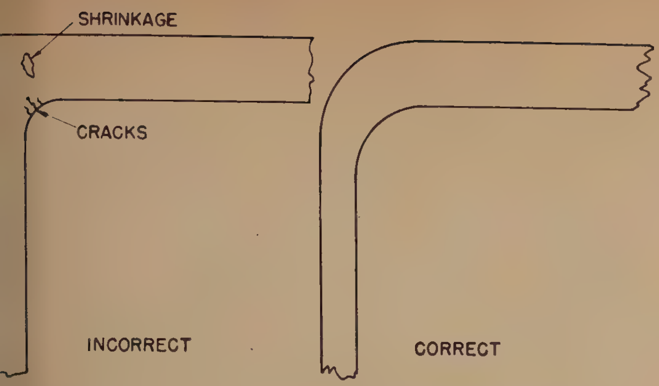


Fig. 13. Incorrect and correct methods of joining thick and thin walls casting

Unfortunately, the attempted application of directional-feeding techniques to faulty designs nearly always increases manufacturing costs and is not always consistent in producing shrinkage-free castings. The least expensive and by far the most effective method of controlling solidification is through proper casting design. If the sections of a casting are proportioned so that there is an uninterrupted, positive temperature gradient starting at the point most distant from the feed metal and ending at the feed metal itself, the design is immune to major shrink cavities. Such cavities occur only when the supply of feed metal fails.

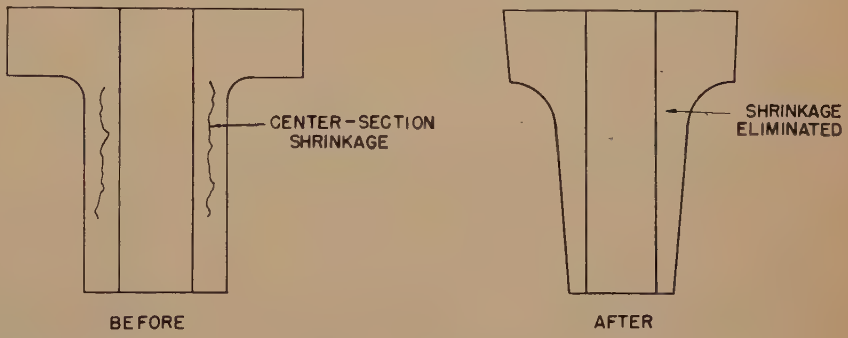


Fig. 14. Elimination of center-section shrinkage through the application of controlled solidification

FIG. 9 illustrates the inscribed-circle method for determining the location of "hot spots" (isolated portions of extra mass which interrupt directional feeding). In this example, the section thicknesses inscribed by r_1 are less than the thickness at their intersection, inscribed by r_2. Therefore, the demand for liquid metal at the intersection will not be satisfied and a shrink cavity will result.

This defect, inherent in the design, can be eliminated on the drawing board by designing the junction as shown in FIG. 10.

Another troublesome section and its correction are shown in FIGS. 11 and 12.

FIG. 13 shows the correct and incorrect methods for joining thick and thin walls.

The examples shown are elementary; however, sections such as these are present in nearly all castings and incorrect design will result in undue repair costs and manufacturing delays. They are shown here mainly to illustrate the simple and inexpensive corrections that can make a reduction in the number of costly defects inherent in improper design.

For many years, a flanged pipe has been a popular casting. Until a few years ago, the foundries produced this casting to the satisfaction of their customers. The advent of commercial radiography changed this situation; when the castings were subjected to x-ray examination, a defect was discovered—center-section shrinkage.

The high temperatures and pressures to which this casting was subjected while in service demanded that the defect be eliminated. Controlled directional solidification was the answer to this demand; it was obtained through alteration of the design to eliminate the source of trouble. FIG. 14 shows "before" and "after" sections of a flanged pipe casting.

Another example of a "hot spot" is shown in FIG. 15. A boss added to the wall of this production casting interrupted the controlled supply of feed metal. While other methods of eliminating this hot spot and the resultant shrinkage were inconsistent, and excess repair cost and time loss were required when the boss was drilled and tapped, a change in design quickly eliminated the defect. The draftsman had but to make a simple change (FIG. 16) and shrinkage was eliminated.

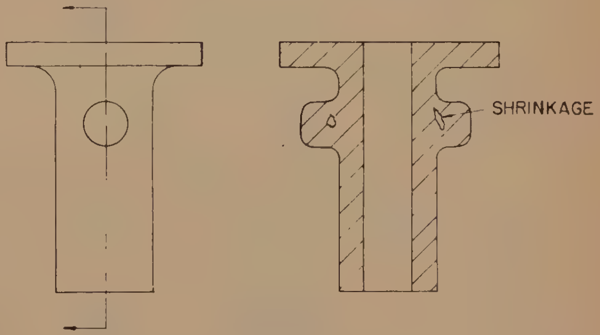


Fig. 15. Shrinkage fault resulting from the incorrect design of a boss

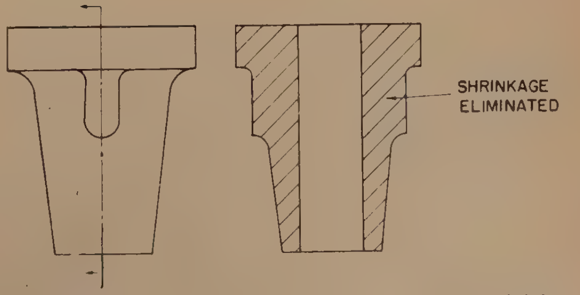


Fig. 16. Redesign of casting shown in Fig. 15 to eliminate shrinkage

The simple flanged pipe becomes extremely complicated to cast when it is added to a larger body as a minor part. The following paragraphs are a brief account of how discussion and agreement between the foundry engineer and designers resulted in a change in design which effected large savings in production.

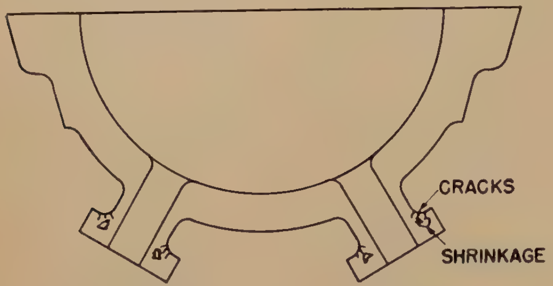


Fig. 17. How shrinkage results from flanged connections on large castings

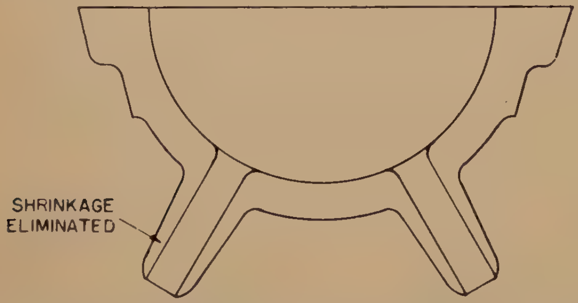


Fig. 18. Redesign of flanged pipes to avoid shrinkage and permit welded connections

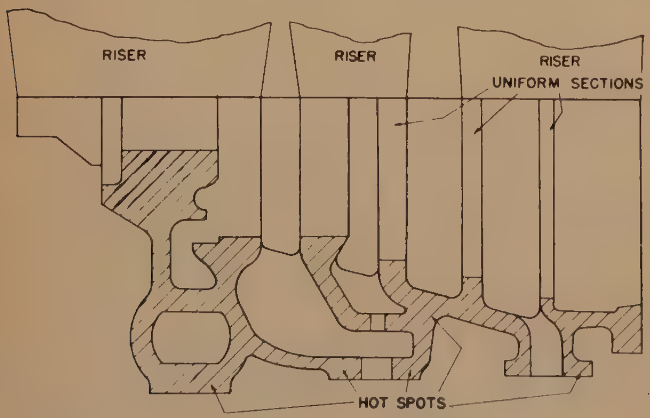
During the design of a new machine, mention was made of the consistent trouble experienced with flanged connections (Fig. 17). It was recommended that the flange be removed altogether and a welded joint used instead. After conferring with the designer and installation personnel, it was decided that such a welded connection would serve the purpose better than the bolted connection. Here, joint discussion revealed more than one reason for a change in design and has resulted in a better casting, a smoother production cycle, and a lowering of over-all costs. The final design is shown in Fig. 18.

If proposed castings are discussed with the foundryman during the early stages of their design, trouble-some areas can be discovered and corrections applied before damage results. Because of his experience and first-hand knowledge of his particular foundry, the foundryman is in a position to make recommendations which should be considered and evaluated before the design is completed.

At this point it is well to warn against the often prevalent attitude, "give it a try as designed." This implies that if the foundryman's prediction becomes a reality, then changes will be made. Such design changes made after failure of the original design, usually involve great expense as well as lost time. For these reasons, a thorough study should be made of the foundryman's recommendations and requests.

A major casting-improvement program has been initiated at the Schenectady Works in the production of a certain large part. These parts, as originally designed, had caused serious losses in production time; and repair costs were equivalent to the original casting costs. Because of its application, the casting is subjected to an extremely critical inspection; after devoting years of effort to the elimination of defects, the foundry recommended certain design changes which would incorporate a cast-and-welded structure.

The proposal was thoroughly studied. It was noted that the planned machining and welding costs were increased over those required in the original design but that the design was such that casting improvement was inevitable. Permission was granted to produce a limited number of castings to the new design and the results have been extremely satisfactory. All of the personnel concerned with these castings are of the opinion that a great improvement has been obtained. The manufacturing schedule is being maintained because of the improved quality of the parts. Cleaning time has been reduced to a mere fraction of that required heretofore. Repair costs have been reduced from 50 to 80 percent of the previous normal values. Foundry costs have been lowered and foundry yield has been increased. In summary, everyone has benefited from the change—primarily a change in basic casting design. Figs. 19 and 20 show the casting before and after redesign.



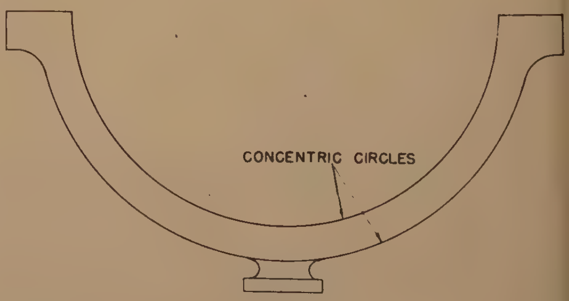


Fig. 19. Original design of a casting of rather intricate section

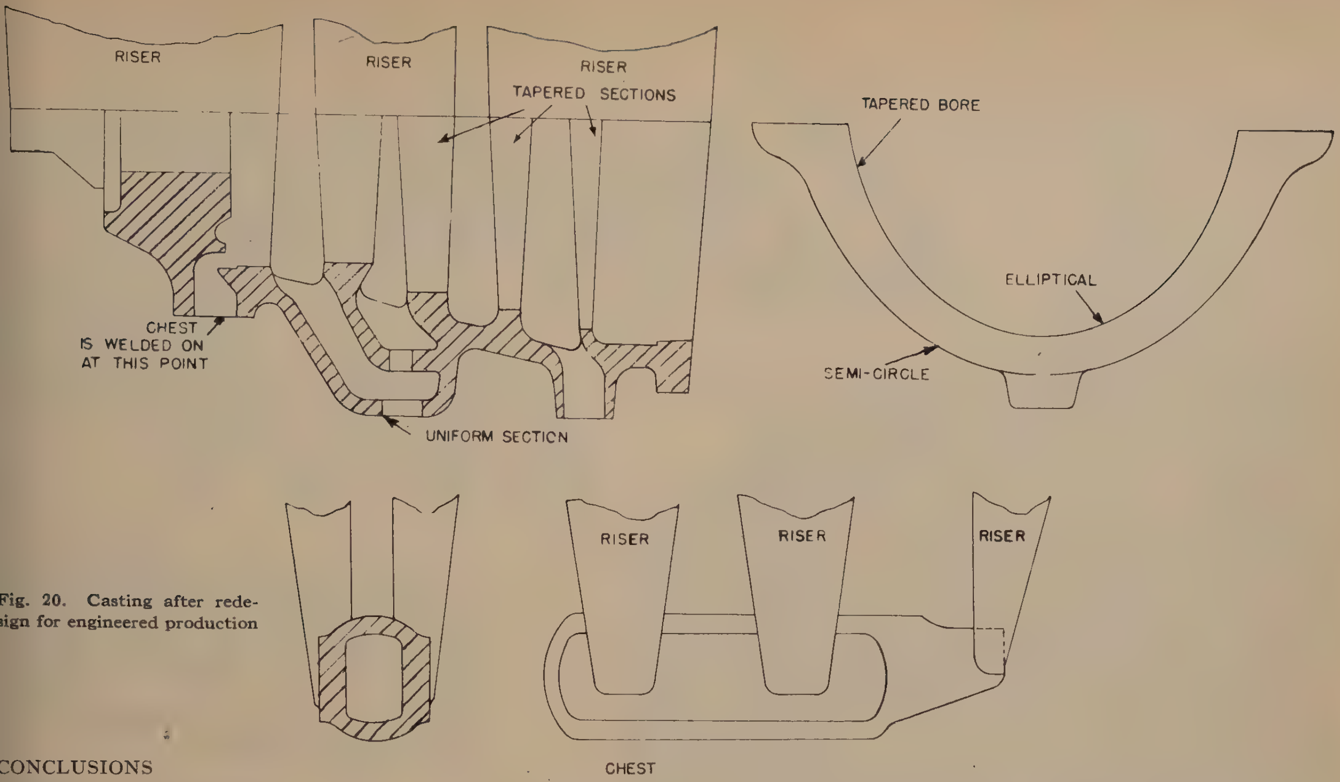


Fig. 20. Casting after redesign for engineered production

CONCLUSIONS

Ever-increasing demands from industry have caused foundrymen to fully realize that their product must be an engineered casting. To achieve this result, close liaison between designer, foundryman, and fabricator is required; a sound casting must be conceived on the drawing board, born of sound foundry practices, and reared to its ultimate application by proper methods of fabrication.

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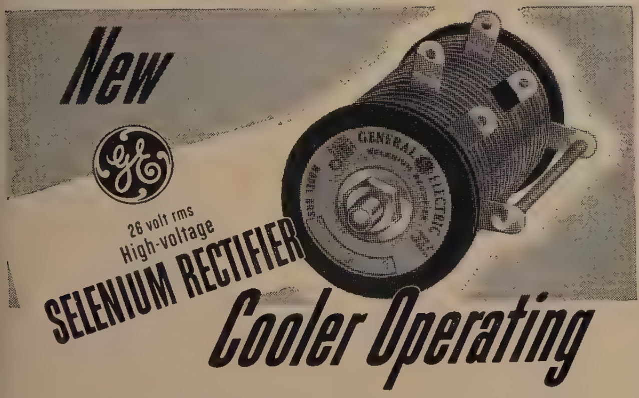

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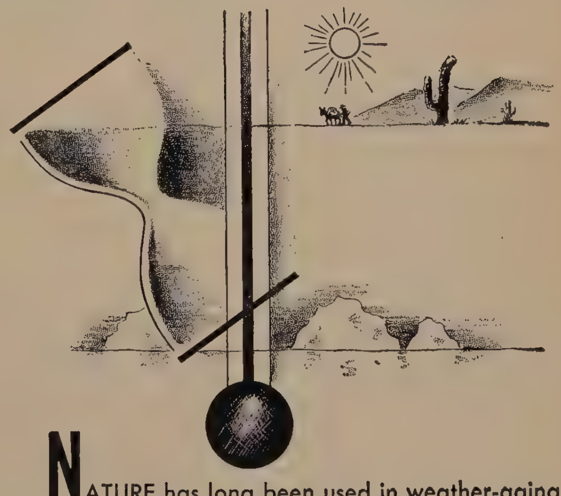

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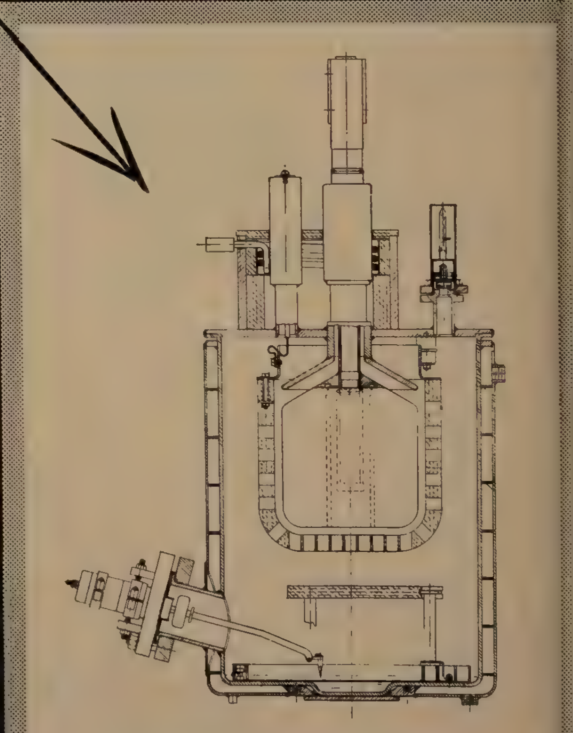

Cross section of pumpless ignitron tank

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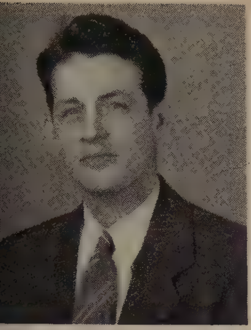
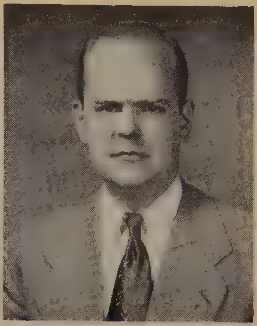
AN INSTRUMENT FOR MEASURING MAGNETIC HYSTERESIS



J. W. Apperson

Its operating principle and convenient utility in testing ferromagnetic sheet material. Also, simple explanation of phenomenon of magnetism, with special reference to rotating and alternating hysteresis

By J. W. APPERSON and E. F. HANSEN
Thomson Laboratory, General Electric Company
Lynn, Mass.



Elmer F. Hansen

THE magnetic force in air gaps of electric generators, motors, and magnets is the all-important oupling link in the transformation of mechanical nergy into electric energy or vice versa. In transormers the magnetic force is again the coupling link, n this case between electric energies at various levels f potential. To construct efficient and compact appaatus, it is usually necessary to provide paths of low eluctance and minimum size for high-density magnetic ields. Iron and some of its alloys, which have higher ermeability and higher saturation density than other naterials, consequently find considerable application n magnetic circuits.

In addition to high permeability at high flux densiies, magnetic circuit materials must generate a mininum of heat in the presence of alternating or rotating nagnetic fields. This core loss, or power wasted in the ore, is comprised of eddy-current loss and hysteresis oss. In general, eddy-current loss can be minimized y dividing the magnetic circuit into parallel planes r laminations insulated from each other, at the same ime using materials of maximum possible resistivity. Iysteresis loss can be minimized by utilizing materials, uch as extremely pure stress-free iron, which are nown to have a low hysteresis constant. As usual, a ompromise is necessary to obtain the best over-all haracteristics, influenced strongly by economy. In onsequence, wide use is made of silicon-iron alloy heets and strips for they have excellent quality for umerous applications.

Due to the variety of types of magnetic steels availble and the metallurgical difficulties involved, it has ecome standard practice for electrical manufacturers o maintain control of incoming materials by specificaions of magnetic properties and by programs of aceptance testing using standardized magnetic test rocedures. Acceptable materials are fabricated, procssed, and then assembled into the electrical apparaus. Operating tests of the apparatus finally indicate vhether magnetizing current and core losses are aceptable. Inferior magnetic materials detected at this final stage can prove to be very expensive, due to failure to meet apparatus specifications and to the cost of rebuilding, with consequent delay in schedules.

Apparatus designers are becoming increasingly conscious of the detrimental effect of mechanical stress on magnetic materials. Stress tends to seriously lower permeability at densities below saturation and also greatly increases hysteresis loss. Incoming materials are passed or rejected on the basis of a few percent excessive core loss, whereas subsequent fabrication and assembly may be capable of increasing hysteresis loss 100 percent or more, with resultant increase in total core loss of approximately 50 percent or more at 60 cycles per second.

Modern processing methods eliminate the detrimental effects of mechanical stress by suitable high-temperature annealing under the control of competent metallurgists. To obtain complete control of the annealing cycle, however, additional magnetic testing of sheet steels or assemblies after annealing has proved of great value. Tests at this stage show the variations in magnetic quality from one furnace load to the next and point the way to obtaining improvement in average quality and also better uniformity. The requirements for such magnetic-test methods are somewhat different from the conventional acceptance tests. Here, speed of testing is of increased importance. If a special sample is necessary for control testing, in applications where an actual assembly part of the apparatus under construction cannot conveniently be tested, then low weight and low cost of the test samples become important since the material in samples is scrapped after tests.

Simplicity is necessary so that a high degree of technical skill is not required by the test man. Reasonable accuracy is required. Comparative-type measurements based on calibrated standard samples are usually quite satisfactory. Such test procedures, properly introduced after the annealing cycle, serve to fill the gap in control of magnetic sheet material between acceptance tests of material and final test of the completed apparatus, especially when fabrication and annealing processes produce considerable change in the magnetic properties.

This article is so paged that, without mutilating other articles, it can be eadily removed for filing as a group of full-size consecutive pages.—EDITOR

IMPROVED TESTING PRACTICE

This article will describe a method particularly applicable to control testing of magnetic sheet and strip. Similar and also quite different methods have been used on assemblies such as unwound or wound stator cores, rotors, transformer cores, etc.

Modern practice is to purchase silicon-steel sheets in the unannealed condition. The acceptance of such material is, however, based on tests of representative samples which have been properly annealed. Laminations of the desired shape are punched from the material in the condition as purchased, followed by an annealing treatment which develops the final magnetic properties of the laminations.

When properly controlled, that testing practice is superior to the previous one of punching finished laminations from mill-annealed sheets. The modern practice not only removes from the laminations the deleterious stress effects of shearing but also develops lower core-loss properties in the material than is possible when mill-annealing the same sheets. The reduction in total core loss resulting from annealing is largely due to reduction of the hysteresis component. Eddy-current loss is affected to a lesser degree. Since the hysteresis loss is the component of loss associated with rolling and shearing stresses, a control test seemed desirable which would test for hysteresis loss only. Stress changes would cause a greater percentage change in hysteresis loss than in total loss.

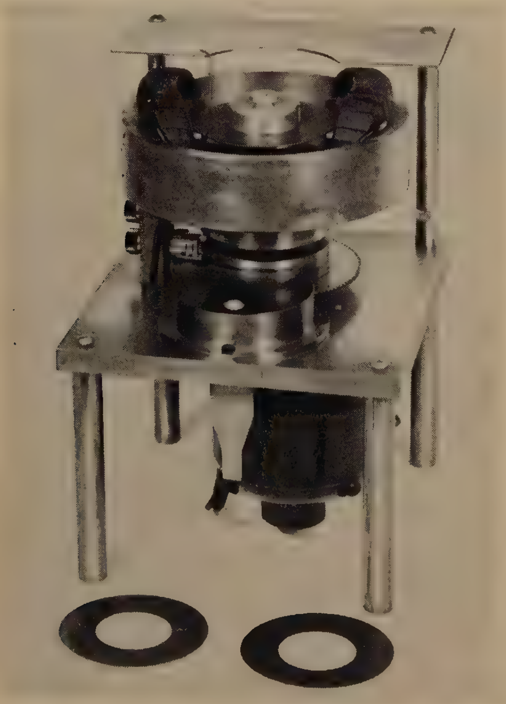


Fig. 1. Basic instrument for measuring hysteresis torque

The need and requirements for improved test equipment to accomplish the described purpose were recognized. It was decided to use the magnitude of hysteresis loss as a guide to the effectiveness of the annealing cycle. A single lamination was desirable as an economical sample, suitable for placement at various locations among stacks of laminations in the furnace. Simplicity demanded the minimum number of winding turns on the test sample for magnetizing and pickup coils.

Fig. 2. Basic instrument in cabinet with built-in rectifier power supply and controls

Those requirements were met by the development of the instrument which is described in this article and which rapidly measures hysteresis loss of a single lamination without the need of winding on any turns. This instrument utilizes the average hysteresis torque developed in a 3-inch diameter 0.025-inch thick lamination by a low-frequency rotating field. The torque, opposed by instrument-type spiral control springs, causes an angular deflection of the punching. This deflection is read directly on a scale calibrated in degrees. FIG. 1 is a view of the basic instrument. FIG. 2 shows the instrument as built into a steel cabinet with rectifier power supply and controls.

It is expected that this equipment will be found useful for many purposes in both factory and laboratory. It should be particularly useful in the fields of magnetic research, development, and education.

DESCRIPTION OF INSTRUMENT

A cross-section view of the basic hysteresis torque instrument is sketched in FIG. 3. A brass baseplate supports a rigid vertical hollow brass center post. A rotating two-pole magnet structure is fastened to an

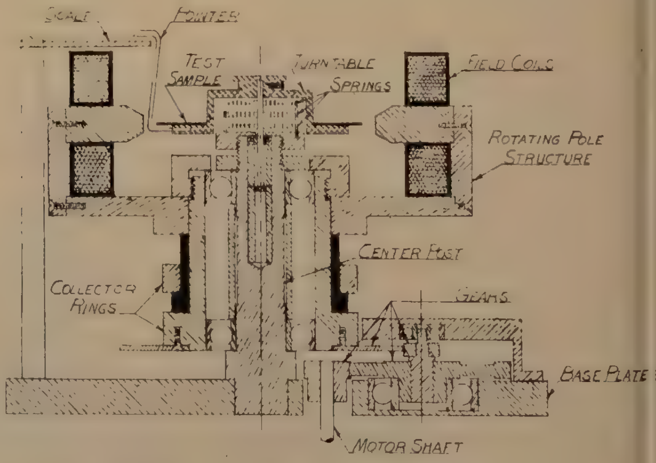


Fig. 3. Cross-section sketch showing construction details

outer hollow bronze shaft which turns on ball bearings supported by the center post. Collector rings on the outer shaft feed magnetizing current to the windings on the rotating poles. The ring-shaped test lamination s placed on the central aluminum alloy turntable which is fastened to a small inner shaft with a miniature pivot ball bearing at the bottom end and a miniature radial ball bearing at the top. Control springs are mounted beneath the turntables. A pointer attached to the turntable passes up through the gap between sample and rotating poles to the horizontal calibrated scale.

The pole structure is rotated at low speeds, in the range of ½ to 3 revolutions per second, by an adjustable-speed motor and reduction gears. Magnetizing direct current is supplied from a 115-volt 60-cycle source by means of a selenium rectifier and smoothing filter ircuit and measured by an ammeter. A circuit diagram s shown in Fig. 4. A neon lamp flashing at 60 cycles per second, periodically visible through holes drilled n one of the gears, serves as a stroboscopic indication f rotational speed.

The speed is in general not critical since hysteresis orque in a homogeneous circular sample is independnt of speed. Directional properties of sheet and strip teels; however, tend to cause periodic variations in reluctance torque which are averaged out on this intrument, except at the higher flux densities. Increased peed tends to reduce these fluctuations. However, the peed cannot be increased too much at high flux ensities since eddy-current torque is then no longer egligible.

Preliminary calibration of flux density versus magnetizing current in several samples was accomplished y using the conventional overdamped ballistic galvanometer method. For these calibration tests, the test samples were wound with 50 turns of 0.005-inch wire for pickup windings as shown in Fig. 5. The wound samples were placed on the turntable which was locked in position with the pole axis aligned with the coil axis. With pickup coils connected to the ballistic-galvanometer circuit, the galvanometer deflections were noted upon reversal of field current after a cyclic condition was first reached. These deflections were converted to magnetic induction by calibration of the galvanometer with a standard mutual inductor. Curves of flux density versus magnetizing current of four samples annealed through a range of different temperatures indicate that the flux density varies only a few percent for samples annealed at these temperatures. The flux density of an unannealed sample is considerably lower at values below saturation. These results indicate that in the expected range of annealing temperatures the flux density will be relatively independent of permea-

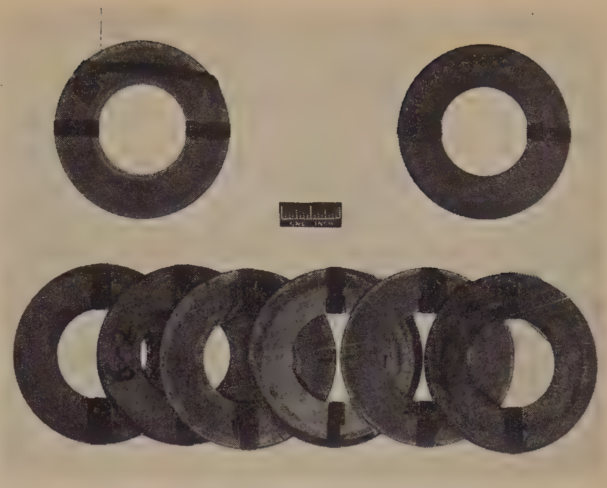


Fig. 5. Test samples wound for flux calibration

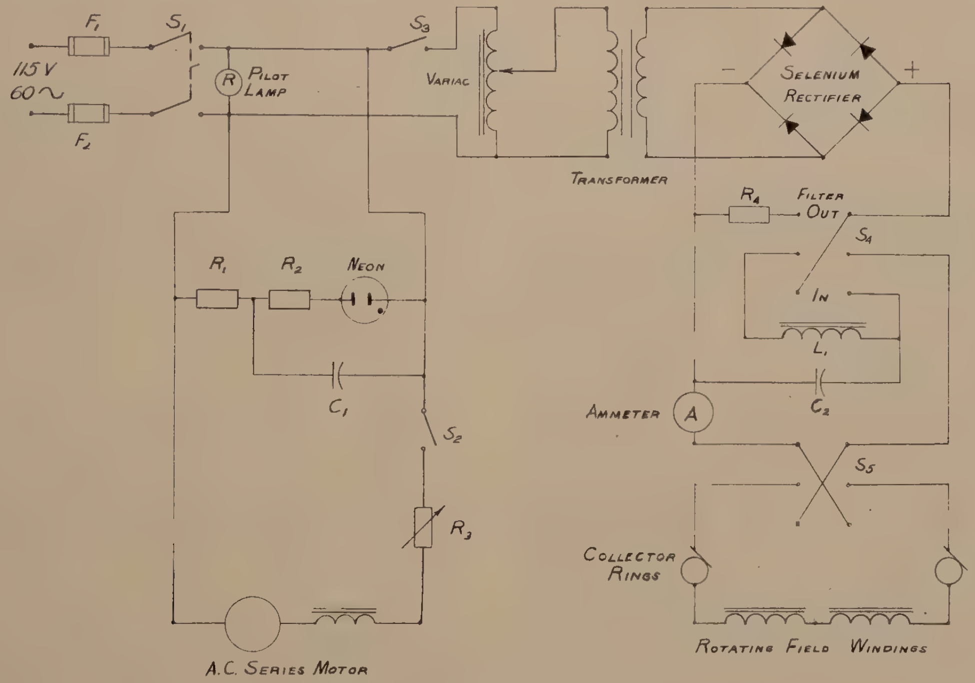


Fig. 4. Circuit diagram of the hysteresis instrument

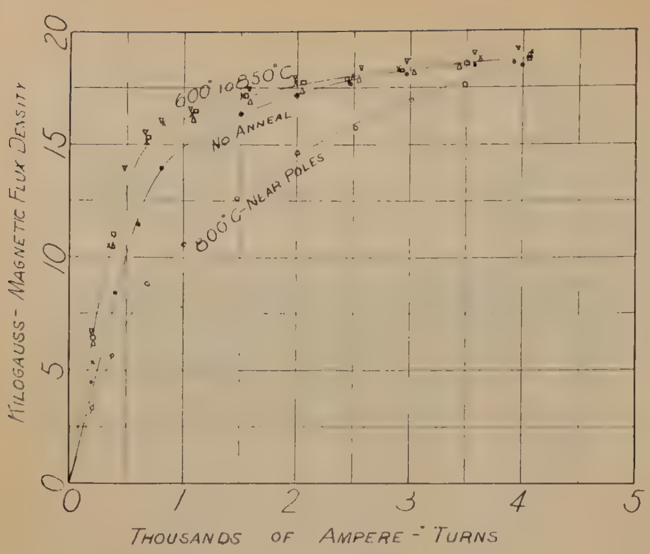


Fig. 6. Calibration curves of flux density vs. ampere-turns

bility of the sample, because of the large air-gap of the instrument. These curves are plotted in FIG. 6.

An additional curve plotted from readings on a pickup coil closer to the pole piece on one sample shows lower flux density in that region, indicating (as expected) that the flux density is not uniform throughout the sample. Actually, a disk shape instead of the ring shape would have approached more closely the ideal ellipsoid of revolution. The ring shape was selected in order to provide a convenient shape for comparison tests by other methods.

Hysteresis-torque measurements were made on the same samples. The indication in angular degrees of deflection was then converted to hysteresis energy loss and power by multiplying by appropriate conversion factors. Application to the test data obtained on the five samples previously calibrated results in the curves of hysteresis energy and power loss versus flux density shown in FIG. 7.

These preliminary curves on a dynamo grade of sheet steel are compared with two experimental curves obtained by Brailsford on two grades of dynamo sheet steel. It can be seen that the curve shapes are approximately similar. As flux density increases, the hysteresis loss increases until a peak value is reached near the knee of the saturation curve. Then, as saturation is approached, the rotational hysteresis begins to drop off rapidly. The unannealed sample, which is in a stressed condition as a result of rolling and punching, has considerably higher hysteresis loss than the annealed samples. As these stresses are eliminated by annealing, the loss decreases. Additional curves on two different grades of steel are plotted in FIGS. 8 and 9. For rapid checks of the effectiveness of the anneal, the data show that one or two values of flux density near or below the knee of the saturation curve will be sufficient.

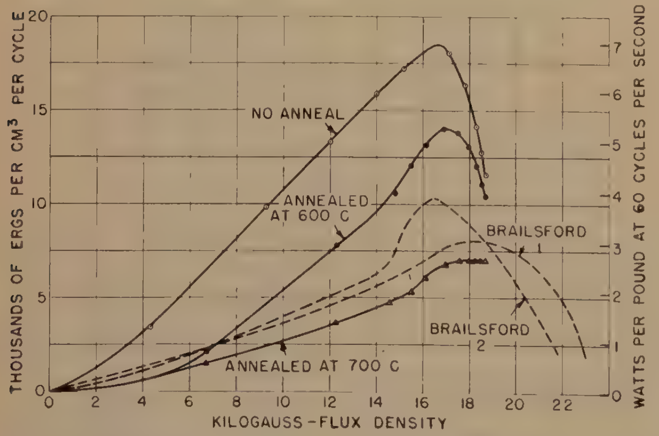


Fig. 7. Preliminary test results on a dynamo-grade sheet steel annealed at various temperatures, and also Brailsford's results on two dynamo-grade steels

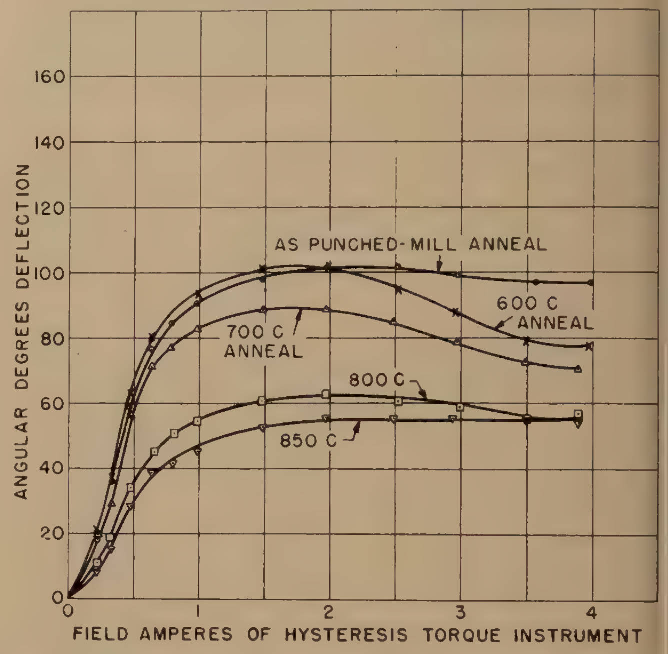


Fig. 8. Hysteresis torque vs. field current for common-grade silicon-steel sheet annealed at various temperatures (preliminary results)

THEORY OF MAGNETISM

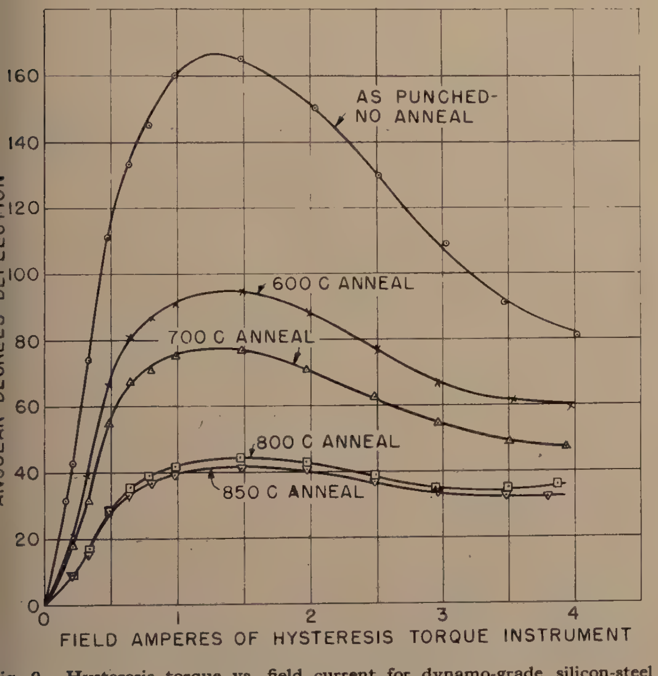
It is readily apparent from these curves, and has been previously established by others, that rotational hysteresis curves are different in magnitude and shape from alternating-hysteresis curves. Rotational hysteresis loss rises to a peak value at the knee of the saturation curve and then falls off apparently to zero at saturation. On the contrary, alternating-hysteresis loss apparently rises exponentially approximately according to Steinmetz' law (alternating-hysteresis energy per cycle: $W \propto B^{1.6}$) to below the knee of the curve and then continues to increase linearly to saturation.

Brailsford has obtained experimental data on four grades of sheet steel which indicate that for corresponding low values of intensity of magnetization the rotational hysteresis loss is more than twice the magnitude of alternating-hysteresis loss. As intensity of magnetization increases, the ratio of rotational to alternating loss decreases until the knee of the saturation curve, where the two losses are equal. As saturation is approached, the ratio of rotational to alternating loss decreases markedly and approaches zero at saturation. The approximate shapes of Brailsford's curves are shown in FIG. 10.

The difference between rotating and alternating ysteresis is not widely known. Such knowledge is nportant to the designer of rotating machinery since oth rotating and alternating-hysteresis losses are resent. The rotating type is found in the steel behind he teeth in rotating armatures or alternating-current achine stators. Alternating hysteresis is found particularly in the teeth. As a loss, hysteresis is undesirble (except in low-frequency induction heating). Howver, rotating hysteresis torque is extremely useful in he hysteresis motor and for starting other types of otors. It also is of great value in hysteresis clutches.

The fundamental difference between the two types f hysteresis results from the action of the magnetic eld. Rotational hysteresis results when a magnetic eld of constant magnitude changes angular direction n a ferromagnetic substance. Alternating hysteresis esults when a magnetic field of fixed angular direction hanges in magnitude (it may assume positive and egative values).

The mathematical explanation of the phenomena of erromagnetic hysteresis has not yet been formulated ompletely. The qualitative explanation requires an ntimate knowledge of the physical structure of maerials and its relationship with present-day ferronagnetic theory. In view of the previously published xplanations of hysteresis (some of which are listed at he end of this article), only a brief explanation will be ttempted here.



ig. 9. Hysteresis torque vs. field current for dynamo-grade silicon-steel rip annealed at various temperatures (preliminary results)

Ferromagnetic materials (iron, nickel, cobalt, and ertain alloys which may or may not include these hree elements) appear to be made up of millions approximately 10^8 per cm^3) of microscopic and subicroscopic permanent magnets. These magnets, known s Weiss domains, are not all of the same size. Furthermore, the size and shape of any given domain does not necessarily remain fixed. The direction of magnetization throughout a given domain is the same. However, the direction of magnetization in a neighboring domain will in general be different. This condition requires a boundary region between domains where a gradual change in orientation exists between different directions of magnetization of neighboring domains. The domains are magnetized completely to an essentially constant intensity of magnetization at all times unless the temperature passes through the Curie point, above which all ferromagnetism disappears. As temperature is again lowered below the Curie point, ferromagnetism spontaneously reappears.

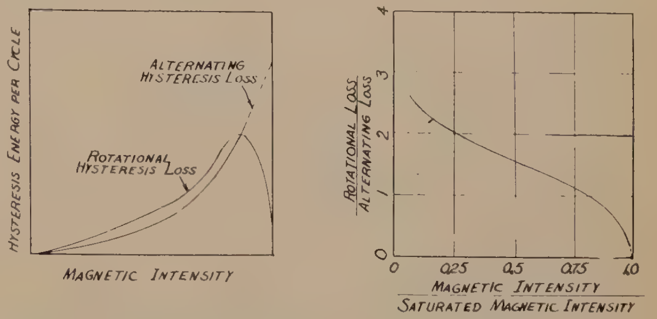


Fig. 10. Comparison of rotational hysteresis loss to alternating-hysteresis loss according to Brailsford

The domains are imparted with magnetism as a result of the alignment of still smaller and more numerous atomic permanent magnets (approximately 10^{15} atoms per domain). These atomic permanent magnets are in reality elementary electromagnets since their magnetic energy exists as a result of a net moment of electron spin which is not balanced out by electrons spinning in opposite directions. The net magnetic effect due to electron orbital motion is small compared to the spin effect. An unbalanced condition of electron spins exists only in ferromagnetic substances. The electron, which is an electrostatically charged particle, when spinning constitutes an effective circular current which in turn constitutes a magnetic field. Spinning electrons in an atom tend to align themselves so that the energy is a minimum.

Neighboring atoms in ferromagnetic materials tend to align themselves so that the net electron spins are parallel. The energy required to maintain this alignment is called quantum exchange energy, the bond resulting from the ability of atoms to interchange electrons without resultant change in energy. The exchange energy tends to build up the volume of each Weiss domain by "robbing" border-line electron spins from neighboring domains by causing spins in one domain to change direction and become parallel to spins in a neighboring domain.

The elementary electron spins are also acted on by anisotropic energy which tends to maintain a perfect crystal-lattice structure of atoms. The anisotropic energy tends to orient neighboring atoms in such a way as to neutralize their magnetic moments. When domains exist within the crystal lattice, the parallel atoms cause a reaction with the anisotropic force and that results in strains and distortion of the crystal lattice. This lattice energy also results in various directions of easy magnetization of crystals. In iron the easiest direction is along the cube edge, next is along the face diagonal, whereas the most difficult is along the cube diagonal. The anisotropic energy also accounts for magnetostriction, the tendency of materials to change dimensions when magnetized. When a material is stressed, the easy directions of magnetization are affected. The direction of tension, for example, becomes an easy direction in iron.

Thus a ferromagnetic material is made up of crystals and the crystals are divided into domains. Crystal energy tends to prevent domain formation which could cause lattice distortion. The domains tend to orient themselves so that the net magnetic energy is a minimum, which involves forming short closed paths of magnetic field. The magnetic energy tends to compress these loops to minimum size, which tends to keep the domain boundaries at minimum thickness.

When a previously demagnetized ferromagnetic substance is magnetized by an external field, the electron spins tend to align themselves parallel to the magnetizing field. As the field is increased from zero through small values, some of the domains which are favorably aligned with the field become larger at the expense of bordering domains not so well aligned, causing a net induced field to appear in the material. This reversible process occurs in the lower region of the magnetization curve where the slope is relatively flat.

As the magnetizing field is steadily increased, the magnetization curve begins to rise more steeply in small discontinuous "Barkhausen" jumps as domains in unstable equilibrium suddenly align themselves and become part of bordering domains whose magnetization was already more nearly parallel to one of the easy directions of magnetization in the crystal. This process is irreversible, but is also accompanied by some reversible magnetization until all domains are aligned with easy directions of magnetization in the crystals which are less than 90 deg from the direction of the magnetizing field.

As the field is increased more, the electron spins gradually are turned into alignment with the magnetizing field without respect for easy directions in the crystal lattice until finally all are aligned. Saturation is reached and the intensity of magnetization can apparently increase no more.

The entire process is controlled throughout by interaction of the exchange energy, the anisotropic energy, and the internal magnetic energy whose stable equilibrium is disturbed by the external magnetic energy.

Alternating hysteresis results when the external field is changed. The irreversible changes cause some domains to remain parallel to easy directions in crystals less than 90 deg from the field direction, whereas in the demagnetized state these domains were aligned with some other easy direction more than 90 deg from the field direction. As the field decreases to zero, residual magnetization remains. The irreversible portion of the magnetization process causes a lag in magnitude of induced field at corresponding values of magnetizing field, resulting in the familiar alternating-hysteresis loop. The irreversible energy appears as heat but the exact cause of the heat is not known. It may be of the nature of an eddy-current loss or viscous friction.

Alternating hysteresis increases with flux density since each alternation requires magnetization changes through all values of field up to the maximum value during the cycle and any increase in the maximum value adds more heat loss to any loss at lower maximum field magnitude.

Rotational hysteresis, however, is not accompanied by changes up and down the magnetization curve. The loss it causes is greater than the alternating loss up to the knee of the curve, evidently due to more irreversible energy changes. Above the knee, however, when the domains are forced into nearly perfect alignment with the field, all electron spin axes evidently rotate smoothly with the constant-magnitude field with less irreversible changes and the loss approaches zero at saturation. The low-magnitude loss is obtained only at the expense of high magnetizing force.

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THE AMPLISTAT AND ITS APPLICATION . . . Part III

Basic principles and problems of circuit design for the application of the amplistat in various regulator, compensating, and control functions

By H. M. OGLE
General Engineering and Consulting Laboratory
General Electric Company

INTERSTAGE PROBLEMS

In the design of multistage magnetic amplifiers great care must be taken to properly match the successive stages. First, the input impedance of the second stage must be properly matched to the output of the first stage. Secondly, the time constant of the second-stage circuit must be so designed as to be consistent with the over-all amplifier time constant. These two factors can usually be taken care of by the proper selection of wire size and number of turns allowed for the second-stage control winding. Care must be taken, however, to insure that maximum output from the first stage will not cause excessive heating of the second-stage winding. In many cases it will be found advisable to use external resistance in series with the second-stage control winding in order to obtain the required speed of response. This will keep some of the power dissipation out of the second-stage control winding.

Most magnetic amplifier circuits are designed to give approximate cancellation of the induced fundamental voltage in the control winding. There is, however, a quite sizable second-harmonic voltage which does not cancel out. The output of an amplistat can be controlled by means of second-harmonic current flowing in the control winding in much the same way that it can be controlled by using d-c. The phase of this second-harmonic current is of course an important factor in determining how much control it can exert.

The amount of second-harmonic voltage induced varies, in general, with the amount of signal applied and with the load current. Depending upon these factors and upon the inductance of the input circuit, second-harmonic currents will flow which will either add to or buck the action of the d-c signal. When designing the coupling between stages in a multistage amplifier, it is usually desirable to prevent as much as possible the flow of this second-harmonic current so that more consistent results may be obtained from the amplifier.

In addition to the second harmonic induced in the second-stage control winding, the output current of the first stage contains a very large percentage of second harmonic. This current can be made use of in a properly designed amplifier to give greater gain per stage than could be realized if only the d-c component were considered. As previously explained, the operation of the amplistat is such that the output current is influenced by the current in the control winding only prior to the firing point. If the firing point of the first stage is designed to occur a few electrical degrees before the firing point of the second stage, an optimum condition will result in which the ripple in the first-stage output will help to produce the largest possible over-all gain.

If the first-stage reactor is too small to properly drive the second-stage reactor, the induced voltage in the signal winding of the second stage may be sufficient to trigger the first-stage reactor and cause loss of control by the signal. This condition can be corrected by the use of extra series resistance or by means of a filter circuit between the stages. A filter circuit will of course increase the over-all time constant of the amplifier, and it is usually preferable to design the first-stage reactor several times larger than is actually needed in order to prevent misoperation of this kind.

REGULATING SYSTEMS

One of the most obvious applications of an amplistat is its use in a voltage regulator. In FIG. 18 a simple voltage regulator for a d-c generator is illustrated. The output voltage of the generator is compared with a reference voltage and the difference is applied to the control winding of an amplistat. This difference, or signal, varies with every change of output voltage. Since the amplistat supplies the field current to the generator, any change in signal will cause a large change in field current. This field current will therefore be of the value required to maintain the output voltage of the generator. As the amplistat is considerably faster

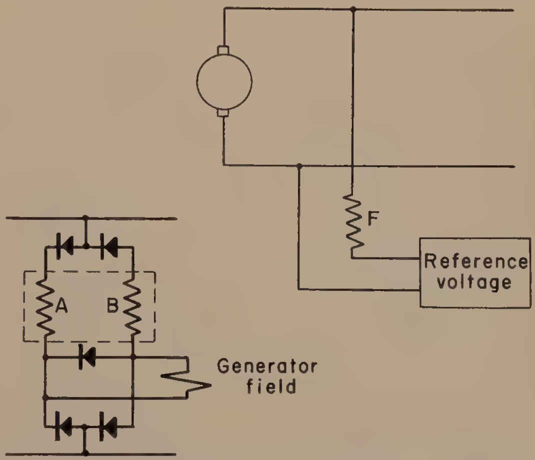

Fig. 18. Schematic diagram showing an amplistat used in a voltage regulator for a d-c generator

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This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR than the field of the generator, this type of voltage regulator usually presents no stabilizing problem.

The commutating rectifier shown in Fig. 18 is used to prevent the inductance of the field from hindering the operation of the amplistat. This same type of voltage regulator can be applied to a-c machines. In this case the alternator output is usually rectified before being compared with the reference voltage.

A voltage regulator for use on an a-c line is shown in Fig. 19. In this case a pair of saturable-core reactors is used to control the output voltage. The control windings of the saturable-core reactors are connected to an amplistat which functions in manner similar to that of the voltage regulator in Fig. 18.

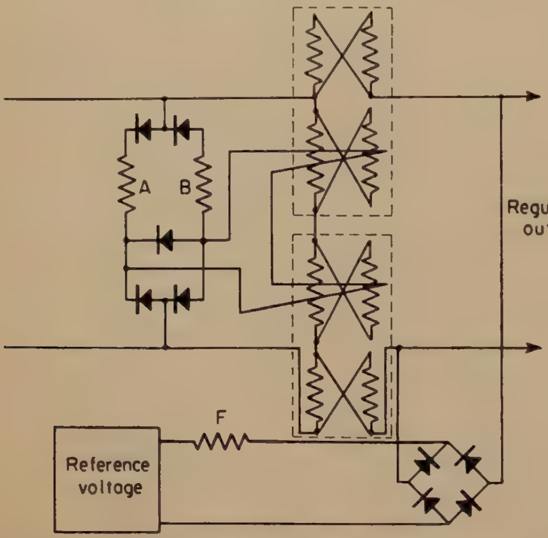


Fig. 19. Saturable-core reactors connected to an amplistat control the output voltage on this a-c line

Generator current can be regulated by a similar system. In Fig. 20 a simple current-regulating system is illustrated in which current is measured by means of a shunt in series with the line. The drop across this shunt is applied to a low-impedance control winding on an amplistat, and a reference winding is so connected that its flux bucks that set up by the main control winding. If the current departs from the called-for value, the amplistat will quickly change the field current to maintain a constant current through the shunt.

The use of a bucking flux in the current regulator in Fig. 20 is frequently found in regulators of other types. Wherever it is desired to isolate the reference from the signal source or to use a different impedance reference and signal source, this method has merit. One limitation of this circuit, however, is that the control windings of the amplistat must dissipate many times the power required for control. The voltage-comparing scheme in Fig. 18 does not have this disadvantage and is therefore used whenever possible.

A very simple speed-regulating system is illustrated in Fig. 21. Here a d-c motor has its field supplied by the output of an amplistat and its speed measured by a tachometer. The tachometer output voltage is compared with a reference and the difference applied to the amplistat control winding. Another speed-regulating syste is shown in Fig. 22 in which the amplistat supplies th full armature power of the motor. Because the moto field is fixed, however, the armature voltage can be use as a measure of speed; hence this system does no necessarily require a tachometer. If the IR drop in th

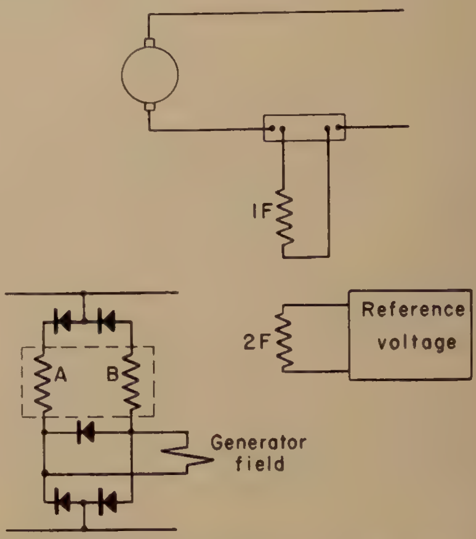


Fig. 20. Current regulator. Constant current is maintained through the shunt by the amplistat

armature of the machine is too great and causes excessive error in this speed signal, IR compensation ma be used. Fig. 23 shows a simple method of IR compensation applied to a speed regulator. For speed-contr systems of high accuracy, however, tachometers a usually used.

Fig. 24 shows a simple positioning system used f remote control. In order to move the load a change made in the position of the control potentiometer. Th difference in voltage between the brushes on the contr potentiometer and the follow-up potentiometer is the impressed upon the control winding of a push-pu amplistat, which drives a split-series-field motor, cau

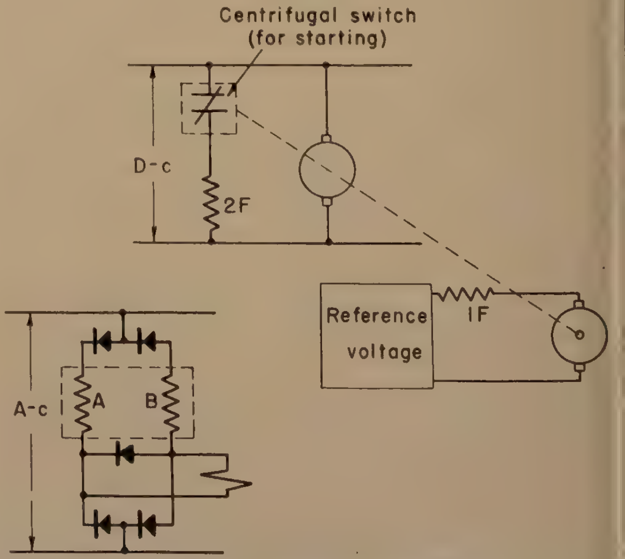


Fig. 21. Speed regulator. A d-c motor has its field supplied by amplista output in accordance with speed measured by a tachometer

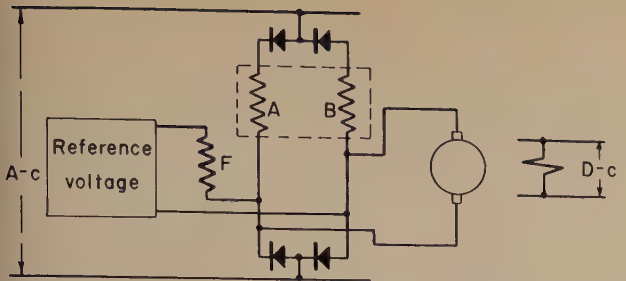


Fig. 22. Here full armature power is supplied by the amplistat acting as a speed regulator

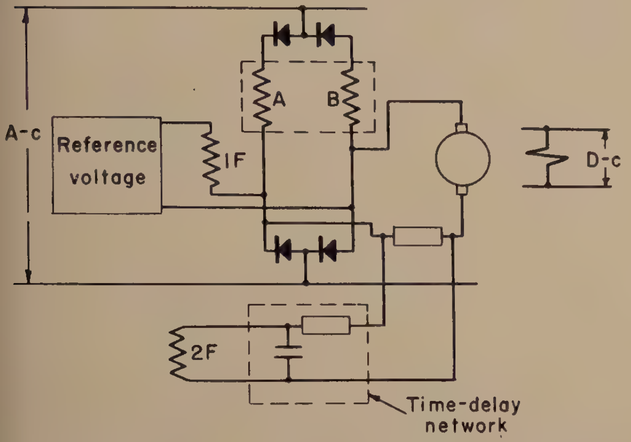


Fig. 23. Simple method of IR compensation applied to a speed regulator

ing it to move the load until the follow-up potentiometer has moved to a position corresponding to that of the control potentiometer.

The amount of torque developed by the motor will, in general, be proportional to the relative displacement of the potentiometers. Such a system may require a stabilizing tachometer, as shown in Fig. 24, which delivers voltage proportional to motor speed. This voltage is connected in series with the control winding. The tachometer tends to regulate the motor speed, making it proportional to the relative displacement of the potentiometers. Selsyns may be used to replace the potentiometers in this positioning system, but in that case the a-c output of the selsyn must first be applied to a discriminator before it can be used to control the amplistat.

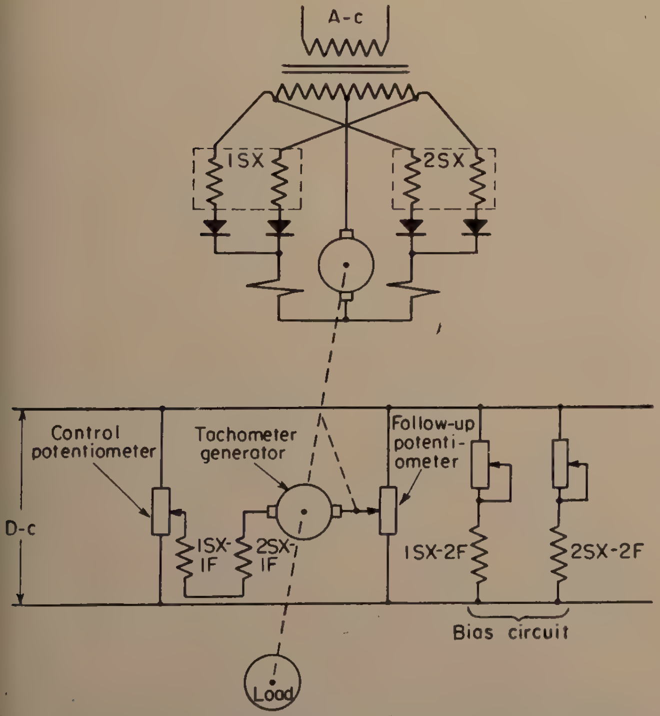


Fig. 24. Positioning system for remote control. A push-pull amplistat adjusts the potentiometers. A stabilizing tachometer may be needed

Temperature-control systems using amplistats can operate either from thermal potentials or resistance change. The latter method is frequently preferred because a larger signal can usually be obtained by it. This is true particularly if a thermistor or similar high-temperature-coefficient material is used, in which case the thermistor would be connected in series with a control winding and a source of voltage. Another control winding is connected in a circuit with a fixed resistor and the same source of voltage. Any small change in the thermistor resistance will cause a change in saturating ampere-turns in the amplistat. Such a system is shown in Fig. 25.

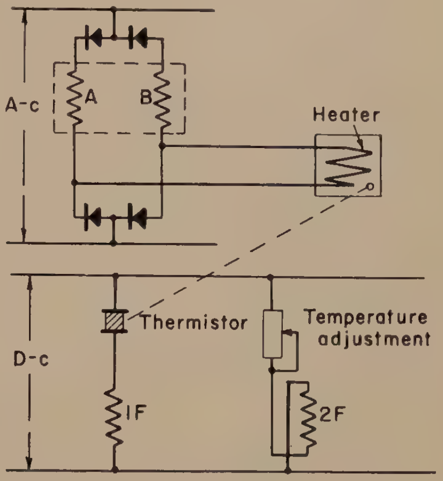


Fig. 25. Amplistat for temperature control, operating from a thermistor

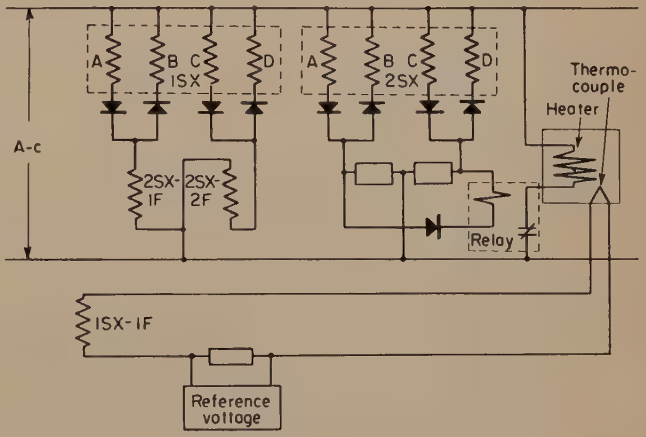


Fig. 26. Thermocouple temperature-control system

The output of the amplistat can be used either to supply the heat directly or to operate some means of varying the heat supply. In Fig. 26 a thermocouple temperature-control system is illustrated. Because of the low level of the thermocouple signal, a multistage amplifier is usually required. In order to minimize the effect of line-voltage variations, push-pull stages are used throughout. The reference is introduced directly in the thermocouple circuit so that the current flowing in this circuit will be kept to a minimum. In addition, each stage of the amplifier operates in the vicinity of zero signal so that changes of amplifier gain will not greatly influence the operation of the control system.

MAGNETIC REFERENCES

In electronic amplifiers it is common practice to use the voltage drop across a gaseous discharge tube as a reference. Such a tube can also be used as a reference for magnetic amplifier circuits. In many cases, however, it is desirable to have a low-impedance device which can be matched more easily to the low-impedance circuits usually found in regulating systems. Two such devices are available to the designer of magnetic amplifier circuits: one is the saturated transformer; the other, the magnetic current reference.

The saturated transformer consists of a primary and a secondary winding, both mounted on a saturable core. The windings are so arranged that leakage flux (flux not passing through the core) from the primary winding will not link the secondary winding. The core is made of material which has a very definite saturation value.

Enough impedance is included in the primary circuit, in the form of leakage inductance or resistance, to limit the primary current flow. Once each cycle the core material will go from full negative saturation to full positive saturation. Thus the secondary winding will experience a change in flux linkages equal to twice the intrinsic magnetization of the core, and during each half-cycle a pulse of voltage will be induced in the secondary winding. The secondary voltage is therefore equal to the frequency times a figure that is dependent upon the material and shape of the core.

Where equipment is to be operated from commercial 60-cycle power lines, the frequency is usually regulated closely enough so that a saturated transformer may be used as a reference. In some applications, two or more saturated transformers are connected in cascade to provide a more precise reference. The output wave shape of the saturated transformer will pose a problem if it is directly coupled to an amplistat input; in most cases, however, the output is rectified and filtered to provide a smooth d-c reference.

For applications in which the supply frequency cannot be depended upon, it is possible to compensate the output of a saturated transformer to reduce the effect of frequency changes. A simpler method is to use a magnetic current reference. This device, which is shown diagrammatically in FIG. 27, consists of a saturable-core reactor so arranged that its core will be forced well into saturation by means of a permanent magnet. The magnetic circuit is very carefully designed so that the introduction of the alnico magnet does not cause an appreciable increase in the reluctance of the a-c flu path.

As can be seen in FIG. 27, this is accomplished b the use of air gaps having very large area as compare with the cross section of saturable core material. Mos

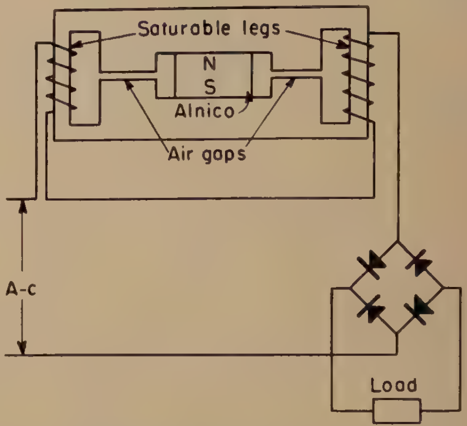


Fig. 27. Permanent-magnet-biased saturable-core reactor provides a constant current for use as a reference

of the magnetic flux set up by the alnico magnet passe through this air gap; a sufficient amount, howeve passes through the saturable core material to cause it t be well above its full saturated value. The two a-c wind ings of this current reference are connected in series i much the same fashion as with any series-connecte saturable-core reactor.

When an a-c voltage is applied to this circuit, curren first builds up in one direction and causes one saturabl core to go even farther above its saturated value, whil the other saturable core is driven back in the directio to demagnetize it. As soon as the latter core reache the knee of its magnetization curve, its flux will begi to change rapidly. This will cause a high induced volt age which opposes the line voltage and tends to mai tain a constant current in the circuit. During the nex half-cycle the cores reverse their functions, causing th current wave shape in the circuit to resemble a squar wave. The height of each square wave is a functio of the strength of the alnico magnet. If the square wav is rectified by means of a bridge rectifier it will resul in a direct current that is a function of the strength o the alnico magnet.

With perfect core material, the current thus associ ated with the magnet would not be affected by suppl voltage, supply frequency, or load resistance. In mos practical cases, however, the output wave shape of th magnetic current reference departs sufficiently from true square wave so that the unit does not act as perfect reference. An additional winding is usuall placed on each core and so connected that an increasin current in this second, or compensating, winding wi cause a decrease in output of the standard. If the com pensating winding is connected to the same source a the standard, it is possible to completely compensat this device over a wide range and make its output in dependent of line voltage. If a large amount of compen sation is required, it may be advisable to frequency-compensate the reference circuit.

MISCELLANEOUS PROBLEMS

Saturation

The amplistat is similar to other amplifiers in that a given unit can deliver only a certain maximum output. If additional signal is applied to the input, only a very small effect if any will be noticed in the output. If in addition to that effect a large negative signal is applied to an amplistat, the signal will cause the core to saturate in spite of the desaturating effect of the load current. Because of this the output current will rise slowly with increasing negative signal until ultimately it may equal the full output current of the amplistat with a normal ositive signal. When two of these amplistat circuits re connected in push-pull, the output current of the ircuit will rise rapidly as the signal is applied until he full saturation value is achieved. If a still larger ignal is applied, the output of the push-pull unit will radually decrease (see FIG. 8, Part II*).

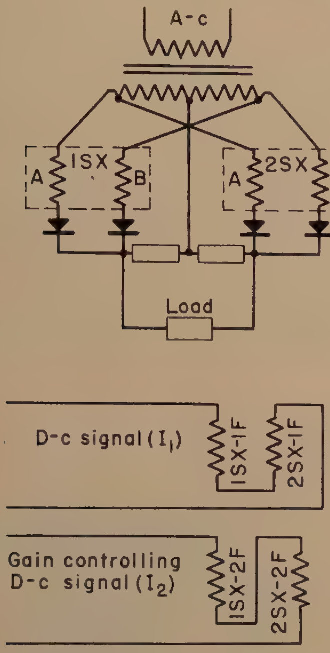


Fig. 28. Circuit by which the gain of an amplistat stage is made to vary in accordance with a d-c signal

In most amplistats it is not possible to put sufficient ignal current through the control winding to reach this egion of operation without exceeding the allowable urrent limit of the winding. If it were possible to put n exceptionally large signal on a push-pull amplistat, he output current would continue to decrease and symptotically approach zero.

In many cases, saturation of an amplifier stage is to e avoided in order to insure linearity in the amplifier utput. In some control circuits, however, it may be esirable to have certain amplistat stages saturate at ome definite value of output. This may be the case where it is desired to have a signal from some source positively override a signal coming from an amplistat. In other cases, saturation of a stage is desired in order to prevent the subsequent stage from being driven too far. Designing a stage to saturate at a definite value usually consists in selecting an operating voltage for the stage which cannot possibly cause too much current to flow in the load.

In a push-pull circuit, such as that shown in FIG. 13 (Part II), it is possible to control the saturation value by adjusting the size of the coupling resistors. If these resistors are set at a very high value, the output of the amplistat will be limited to a low saturation value.

Variable Gain

If it is desired to have the gain of an amplistat stage vary in accordance with a d-c signal, that can be accomplished by means of the circuit shown in FIG. 28. A conventional push-pull amplifier stage is equipped with two extra bias windings, connected so as to vary the operating point of the individual amplistats in the push-pull arrangement. By this means the gain of the stage may be varied from a maximum to zero or even a negative value if so desired. The characteristics of such a variable-gain stage are shown in FIG. 29.

Phase Control

If smooth d-c signals are always applied to amplistat control windings, the output current can be exactly predicted by referring to the control characteristic for the particular amplistat; but if any of the currents flowing in control windings have an appreciable ripple content this is no longer possible. The effect of the ripple content will vary according to its amplitude, its wave shape, and its phase, and will depend upon the firing point of the amplistat.

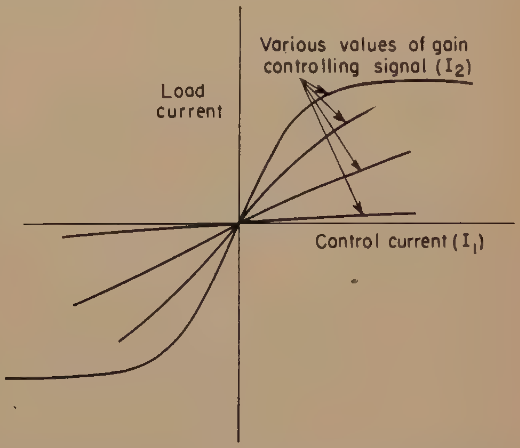


Fig. 29. Control-current characteristic of the variable-gain stage of the circuit in Fig. 28

As the amplistat is affected by the flux condition of the core only prior to firing, the phase of the ripple current may have a large effect upon the operating point of the amplistat. This point is especially important in

(Concluded on following page)

---

*Part I appeared in February issue; Part II in August.

DESIGN ENGINEERS

CAN YOU USE
A RESISTANCE MATERIAL
in which *I varies as E⁴?*

Thyrite may be the answer to some of your circuit problems. It is a silicon-carbide ceramic material, dense and mechanically strong, having nonlinear resistance characteristics—the resistance varying as a power of the applied voltage. Its resistance characteristic is stable, and substantially independent of polarity or frequency. Thyrite® has been used for many years in important applications, including electronic. It can be produced in various shapes and sizes (those which can be successfully molded).

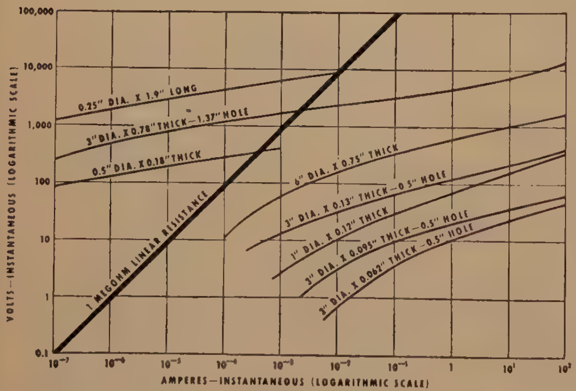
Some of its MANY APPLICATIONS

For protective purposes (to limit voltage surges).

As a stabilizing influence on circuits supplied by rectifiers.

As a potentiometer. (The division of voltage can be made substantially independent of load current.)

For the control of voltage-selective circuits, either independent of or in combination with electronic devices.



Typical volt-ampere characteristics of Thyrite resistors of several resistance levels and power ratings. Note that the nonlinear voltage-current characteristic extends over an extremely wide current range. Compare it with the characteristic (heavy line) of a 1-megohm linear resistor. Apparatus Dept., General Electric Company, Schenectady 5, N. Y.

Contact your nearest G-E office for additional data or address Transformer & Allied Product Divisions, General Electric Company, Pittsfield, Mass.

GENERAL ELECTRIC
405-13

THE AMPLISTAT AND ITS APPLICATIONS

(Continued from preceding pag

designing a critical voltage-regulator application for
a-c machine. If the a-c output of the machine is rectifi
and placed directly on the control winding of an amp
stat, considerable ripple will be present. If filters a
added to this circuit to reduce the ripple, the over-
time constant of the regulator will be impaired.
studying the phase of this ripple and by shifting it with
conventional phase-shift network, it is possible to utili
its effect to increase the apparent gain of the amplista
In other words, if an increase in load on the machi
calls for more field current, the firing angle of t
amplistat will be advanced, causing a change in t
influence of the ripple currents. This change in influen
can be controlled by phasing the ripple currents.

Supply Frequency

Like many inductive devices, an amplistat can
made smaller if the supply frequency is increased. Sin
the smaller an amplistat becomes, the less contr
power is required, it is always advisable to operate
amplistat at as high a frequency as is readily availab
Furthermore, because the minimum period during whic
the control winding can influence the output is one ha
cycle of the supply frequency, shorter time constan
are possible when higher supply frequencies are use

(*Concluded*)

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HIGH LIGHTS AND SIDE LIGHTS

Odor-dispelling Lamp Bulb

The fresh, clean smell which prevails out of doors during an lectrical storm is being reproduced indoors on a small scale y means of a small lamp bulb recently introduced.

Ozone, which has the effect of neutralizing many objectionble odors, is now produced at the flick of a switch by a new, our-watt lamp which is designed to dispel unwanted odors. his lamp bulb is expected to find use in many places where a eodorizing effect is desired.

A glass ball less than an inch and a half in diameter, the new mp bulb gives off the barely noticeable concentrations of ozone at are useful in making the presence of odors less perceptible. t operates on household current and is used with a ballast in a mple fixture which allows the free escape of ozone but shields e eyes from the ultraviolet energy generated by the lamp.

Although they are expected to find wide public acceptance n homes, offices, and other living and working areas, the first zone lamps to be produced are being built into automatic lothes dryers to give clothes the odor as well as the appearance of leanliness. The bulbs also are being built into refrigerators and everage-vending machines, and are seen by engineers as having dvantages in such other equipment as heating, ventilating, and ackaged air-conditioning units.

The ozone produced by one lamp bulb is reported sufficient o mask odors in areas of up to 1000 cu ft, and has a mild ermicidal effect. To help maintain the desired condition of anitation, the lamps are expected to be used in small, sanitary torage cabinets for beauty and barber supplies, medical and ental instruments, and tooth brushes.

Calrod Heater Finds Ingenious Use in New Popcorn Stand

Air blown across the heating unit keeps popcorn fresh and crisp, and carries the aroma out to prospective customers

Modern Equipment for the Paper Industry

At a new multimillion-dollar paper mill in California is the ost extensive and modern installation yet to be made by the aper industry in that state.

For the first time in this worldwide industry, a steam turbine as been applied to drive a log chipper. Under power of a 500-hp turbine, logs 20 ft in length and 40 in. in diameter re reduced to chips at the rate of one foot per second.

Three 5000-kva turbine-generators develop the entire elec-ical energy for the plant. The exhaust from the turbines pro-des the steam for the process of reducing the chips to usable cellulose fibers. After being cooked with steam and chemicals, the chips are transferred by motor-driven pumps to washers for removing the chemicals.

Millions of gallons of water are used to move the cooked chips—now pulp—from one point to another. The water must be conditioned for this use. A number of pumps, driven by motors, supply the water, and in the treatment process Thy-mo-trol adjustable-speed drives add chemicals in accurate quantities according to the amount of water being pumped.

Each section of the paper machine has an individual drive motor, each with its own electronic-amplidyne-controlled supply generator. A master control panel provides stepless speed adjustment throughout the range of the machine, and the speed of each section is automatically maintained in its proper relations.

A regenerative tension-winder drive is used for rewinding the finished paper from the machine roll into shipping rolls. Two motor-generator sets provide charging facilities for a fleet of electric fork trucks, and 70-ton and 44-ton diesel-electric locomotives are used for moving log cars, raw materials, and finished products from the plant.

Missouri Basin Dam by Floodlight

Kortes Dam, being built across the North Platte River in Wyoming, is a unit of the Missouri Basin Project

Metering Emotional Reactions

A sensitive instrument which measures infinitesimal electric currents is providing science with a clue to hidden causes for the misbehavior of problem children.

A photoelectric recorder has been adapted for use with a standard lie detector in determining and recording the emotional response of subjects to various stimuli. The instrument already has revealed a new classification of abnormality which the psychologist experimenting with it describes as "dead pan." The acute sensitivity of the recorder has demonstrated that this type of person has no emotional response to usual stimuli.

Through electrodes taped to the fingers, the recorder detects and makes a permanent record of minute changes in the electric conductivity of the palmar skin. Psychologists have long known that emotional reactions change the electric conductivity of the skin, thus providing a barometer to man's feelings.

The recorder detects current in microamperes. By means of an optical system, changes in the tiny current being measured are relayed to the recording element. The graphic patterns of changes in skin conductances are automatically recorded on paper for study and comparison.

(Continued on following page)

Tempilstik°

the Crayons that tell temperatures

A simple method of determining safe operating temperatures for

- **BUS BARS**
- **POWER TUBES**
- **TRANSFORMERS and other electrical equipment.**

also in:

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- **CASTING**
- **FORGING**
- **DRAWING**
- **HEAT TREATING**
- **WELDING**
- **FLAME-CUTTING, etc.**

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gives up to 2000 readings

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125	275	450	1000	1550
138	288	500	1050	1600
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175	325	650	1200	1750
188	338	700	1250	1800
200	350	750	1300	1850
213	363	800	1350	1900
225	375	850	1400	1950
238	388	900	1450	2000
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FREE —While we cannot supply free Tempilstiks°, we will be glad to send you sample Pellets or sample Tempilaq° (liquid form) for trial under your actual working conditions. Be sure to state the temperature of interest to you.

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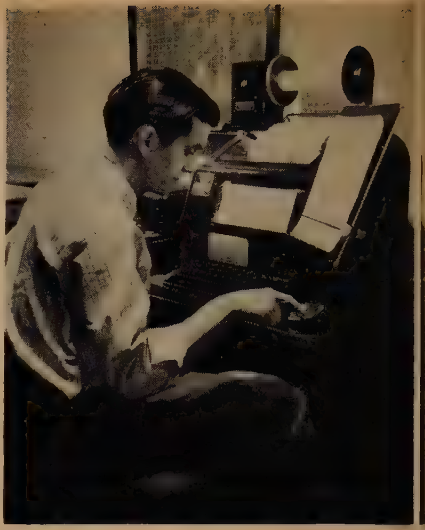
Pipe-line Operation by Remote Control

A "telephone" dial on a dispatcher's desk in a New York City office now operates, by remote control, four new automatic pumping stations on an oil company's eight-inch petroleum-products pipe line almost one thousand miles away.

This new method of pipe-line control, believed to be the first of its kind in the world, was developed to meet the increased demand for petroleum products through the pipe line, traversing Illinois, Indiana, and Ohio, particularly during the winter months, when fuel oil predominates. To meet the required increase, four new pumping stations were installed between the Wood River (Ill.) refinery, near St. Louis, and Columbus (Ohio), each with a single 500-hp pump motor.



Pipe-line dispatchers in New York now have oil at their finger tips—850 miles away

Orders dialed from New York are carried out automatically in this pumping station and in three others like it along the products pipe line

The stations are designed to be as fully automatic as possible so that the dispatcher can start or stop the station and take instrument readings from his desk in New York City.

Teletype relays permit the switchgear to set up a station-run sequence at any one of the four new stations when the proper code letter is dialed in the dispatcher's office. The station-run sequence: (1) starts an oil pressuring pump to lubricate seals in the main pump; (2) opens the motor-operated suction valve; (3) starts the 500-hp pump motor (full-voltage start); and (4) opens the motor-operated main discharge valve to bring the station on the line. Shutdown is then effected by opening the station-run relay, which shuts off the pump motor and simultaneously closes the motor-operated valves. A mechanical check valve in the line permits pipe-line flow to go past the pump when these valves are closed.

Dialing another code letter allows the dispatcher to read the instruments at any one of the four stations in rapid sequence over the teletype system. A pulse-duration telemeter system in the switchgear cubicle, in conjunction with pressure-recording instruments both ahead of and behind the pump and a motor current recorder, causes the teletype to transmit signals which can be read by the dispatcher in terms of instrument readings.

New Instrument Aids in Photography of Air Flow

A new instrument has been designed to facilitate observation and photography of air-flow phenomena. Known as the Schlieren Light Source, the device is a self-contained unit housing power supply, control circuits, lamps, and optical system. It furnishes both continuous and high-intensity-flash illumination.

The Schlieren system operates on the principle that a change in air pressure or temperature produces a change in the air's light-bending properties. The ultimate purpose of the equipment is to reveal graphically the air-flow patterns around high-speed missiles and models of supersonic aircraft in wind tunnels. One such picture is more valuable to aircraft designers than data taken from 100 hours of air-flow calculations. Use of the photographic technique shortened immeasurably the time required to work out new airplane designs during World War II.

Sound and air flow are made to show on photographic film by means of ecial optical systems and brilliant flashes light lasting less than one-millionth of second.

One technique, called shadowgraphing, nsists of throwing a shadow of air on a otographic film for a brief instant. The ash of light used is quick enough to reeze" movement in the air. Areas of high and low air density bend light waves in different ways, so that light waves passing through them contrast as light and dark areas on the film. Sound waves, being narrow areas of high compression, show up as thread-like lines.

A more complicated method, which reveals finer gradations in air density, is called Schlieren technique. Light, having passed through the air being photographed, is focused to a point. After passing through this point, it spreads out again, striking a photographic film. A knife edge is inserted at the focal point just far enough to keep the light from passing to the film; if the air being studied is disturbed, areas of high or low density will form, bending the light so that it passes over the knife edge to register on the film. Hence, light passing through undisturbed air is stopped by the knife edge, while disturbed air shows up on the film.

TRADE LITERATURE

ir Filter—Introduces a new replaceable-type air filter, the mer-Glas made in standard sizes for forced-air heating, ven- lating, and air-conditioning systems. The text covers these nases: operating principle; resiliency; efficiency; maintenance; zes and capacities; installation data; and assembly. Six pages. ılletin 211.—*American Air Filter Co., Inc., Louisville, Kentucky.*

utomatic Controls for Speed Drives—Four basic types—ectronic, hydraulic, pneumatic, and mechanical—for auto- atically controlling the output speed range of P.I.V. variable- eed drive are outlined in this bulletin. A double-page spread devoted to the applications for modern industrial needs. Eight ages. Book No. 2349.—*Link-Belt Co., 307 N. Michigan Ave., hicago 1, Illinois.*

utter—Various models of a new portable hydraulic guillotine ıtter for cutting insulated electric cable and armored cable up 3½ in. o. d. are illustrated and briefly described. Also shown e three portable pump units for use with this cutter. Four ages. Titled "Guillotine Cutters."—*Manco Mfg. Co., Bradley, linois.*

immers—A bulletin describing Radiastat and Autrastat dim- ers, a modern lighting control for use in theaters, audito- ums, churches, colleges, schools, etc. Its suitability for indus- ial or laboratory use also is explained. Typical mounting frame- ork in standard forms is shown. Diagrams and halftones ıpplement the text. Sixteen pages. Bulletin 76.—*Ward Leonard lectric Co., Mount Vernon, New York.*

ilters—By means of easy-to-read diagrams, tables, and cate- orized data illustrated throughout, this informative booklet xplains the advantages, uses, operation, and manufacturing ethods of Surfamax porous stainless-steel filters. Types of lters and their arrangements for various requirements is cov- ed, together with detailed engineering information on dimen- ons and specifications. Eight pages.—*Micro Metallic Corp., 193 radford St., Brooklyn, N. Y.*

ampholders—Presents the complete line of indoor and out- oor Utilite lampholders and accessories, both standard and vivel types, for self-reflecting flood and spot lamps. The variety types for every application—commercial, industrial, and for ome use—are described and illustrated. Color equipment and ccessories are listed. Four pages. Bulletin No. 121-50.—*Steber lanufacturing Co., Broadview, Illinois.*

agnet Wire—Provides complete information on Formex and eltabeston magnet wires. The booklet combines the listing of oth film-type and asbestos- and glass-insulated magnet wires, nd covers the development, properties, applications, advan- ges, and sizes. Test data, graphs, illustrations, and specifica- on tables are included. Attention is given to installation details ıch as methods of stripping, soldering, and welding; and one ction covers varnish treatment. Thirty-two pages. Bulletin -329.—*General Electric Co., Construction Materials Dept., Bridge- rt, Conn.*

Motors—Presents a line of small-power motors of the unidirectional, reversible, and synchronous types for use in a multitude of products and appliances. Tables and curves provide performance characteristics; diagrams furnish wiring and dimensional information; and illustrations show many internal views of parts and components. Thirty-six pages.—*Barber-Colman Co., Rockford, Illinois.*

Radio, Electronic, and TV Products—Over 5000 radio and television products and service aids are listed. Nearly every item is illustrated, with brief details given. A convenient general index is included for ready reference. Sixty-four pages. Catalog No. 154.—*General Cement Mfg. Co., Rockford, Illinois.*

Relays—Technical information is given on a number of hermetically sealed relays which include the radio, telephone, and aircraft types. Coil, contact, and operating data are furnished in detail. Twelve pages. Catalog 5-H.—*Guardian Electric Mfg. Co., 1621 West Walnut St., Chicago 12, Ill.*

Research Administration—"Management of Industrial Research" titles this carefully selected bibliography of books and articles. The contents are indexed under the following categories: general references, both books and periodicals; organization; control; research program, both technical and economic; research laboratory; and miscellaneous topics. Twenty-four pages. *Arthur D. Little, Inc., Cambridge 42, Mass.*

Resins—Complete data on uses of the Paraplex P series resins in the laminating, molding, potting, and casting fields are presented. Tables and charts define the physical properties of the liquid and cured resins. Techniques are suggested for blending, laminating with glass-fiber and other reinforcements, compounding, and curing. The use of fillers, pigments, and dyes is also treated. Twenty-four pages. Titled "Paraplex P Series Resins."—*Rohn & Haas Co., Resinous Products Division, Washington Square, Philadelphia 5, Pa.*

Three-phase Frequency Changer—A descriptive bulletin on the Type CR7503-M three-phase frequency changer for spot and projection welding. Treated in the text are such topics as advantages, application, the why of three-phase welding, operation, equipment furnished, optional accessories, and adjustments. Four pages. GEC-491—*General Electric Co., Apparatus Dept., Schenectady 5, N. Y.*

Timing Devices—Photographs, dimensional drawings, and diagrams assist in presenting a line of electrical timing devices which includes units for time-delay, interval, repeat-cycle, and elapsed-time functions. A brief description of each type gives important features; specifications and ratings, together with ordering aids, are clearly stated. Eight pages. Catalog No. 323.—*Haydon Manufacturing Co., Inc., Torrington, Conn.*

NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

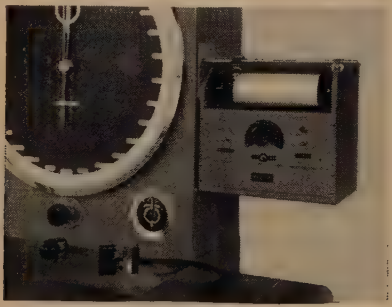
Masonry Drill

A new carbide-tipped Live-Spiral masonry drill has a flute made of piano wire wound in a low helix around the steel shank. The flute is the means of solving one of the main problems in drilling masonry, brick, tile, etc. because dust is removed as fast as it is formed, eliminating the tendency for dust to pack in the holes. Since the drill need not be withdrawn to remove dust, drill life is increased. These drills can be used in most of the ordinary types of floor and wall materials such as concrete, brick, tile, marble, slate, etc., as well as copper, brass, and other soft metals.—*Carboloy Co., Inc., Detroit 32, Michigan.*

Press

A new press, known as the No. 44, designed to meet a long-standing need among die-casting and other manufacturers for a press with extra-long stroke, extra shut height, and extra throat depth. This 35-ton capacity unit has a standard stroke of 6 in. and standard shut height of 10 in. Throat depth is 11½ in. Some of its features include: a removable ball seat; round-type ram clamp; a convenient rear-operated reclining mechanism; Timken bearings; nonrepeat clutch mechanism; and time-saving knockout bracket. The press has a 33 in. by 21 in. bed area and a 24 in. by 8 in. ram face.—*Federal Press Co., Elkhart, Indiana.*

Electronic Recorder



A new electronic recorder provides wide range of magnification in tension, compression, and transverse testing. A single multiposition switch selects magnification of strain from various ratios between 1000:1 and 10:1 without gear changes. The testing machine operator changes from one magnification to another during test without affecting the values of the test data, and the pen repositions itself. Thus the operator knows definitely that a different magnification is being used. For each range, the load scale is spread over 182 in.—*Tinius Olsen Testing Machine Co., 1036 Easton Rd., Willow Grove, Pa.*

Laminating Material

A new ready-to-form laminating material, known as Dryply, has high tensile and flexural strength. This material can be formed under low pressures, or it can be used in presses where high pressures prevail. It consists of glass cloth or mat impregnated with a polyester compound, including catalyst, which comes to the manufacturer dry and ready to use. The material comes in rolls; in use it is trimmed, laid up for forming, and heat cured by conventional methods. Advantages include savings in material, time, and labor costs; low reject rate, and good quality parts. Dimensionally stable, the material will withstand chemical and weather elements.—*Francis D. Gonda Co., 3974 Wilshire Blvd., Los Angeles 5, Calif.*

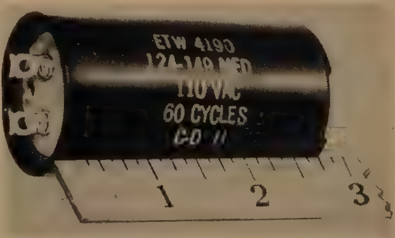
Wheatstone-Megohm Bridge

A new 635-A Wheatstone-Megohm bridge, a highly versa direct-reading instrument, designed for accurate resista measurements between 10 ohms and 1,000,000 megohms. It c be used to measure resistance elements and insulation resistan and to determine the volume resistivity of various materi Basically, the instrument is a Wheatstone bridge used in co junction with a d-c amplifier. Two built-in power supp operating on 115 volts, 60 cycles automatically provide correct bridge voltages for the high and low ranges.—*Shallc Manufacturing Co., Collingdale, Pa.*

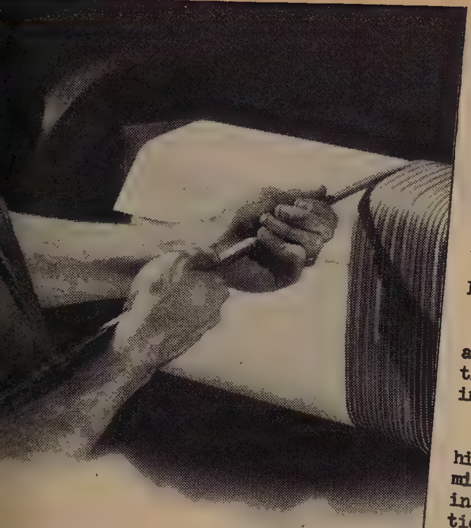
Plastic

A new tough thermosetting plastic, called Enrup, fills need for a high-strength material resistant to abrasion a chemicals, and at the same time can be produced in vary degrees of flexibility, ranging between elastic soft rubber one hand and brittle hard rubber on the other. An outstand use is for the manufacture of high-strength low-cost gears replace metal gears in such applications as heavy-duty lath household appliances, plating barrels, automotive timing vices, and dynamometers. The plastic is particularly sui for washing-machine parts where its resistance to the new type of synthetic detergents has given it an advantage o metal. It is available in the form of sheets, rods, tubes, g blanks, and as molded parts.—*United States Rubber Co., Roc feller Center, New York 20, N. Y.*

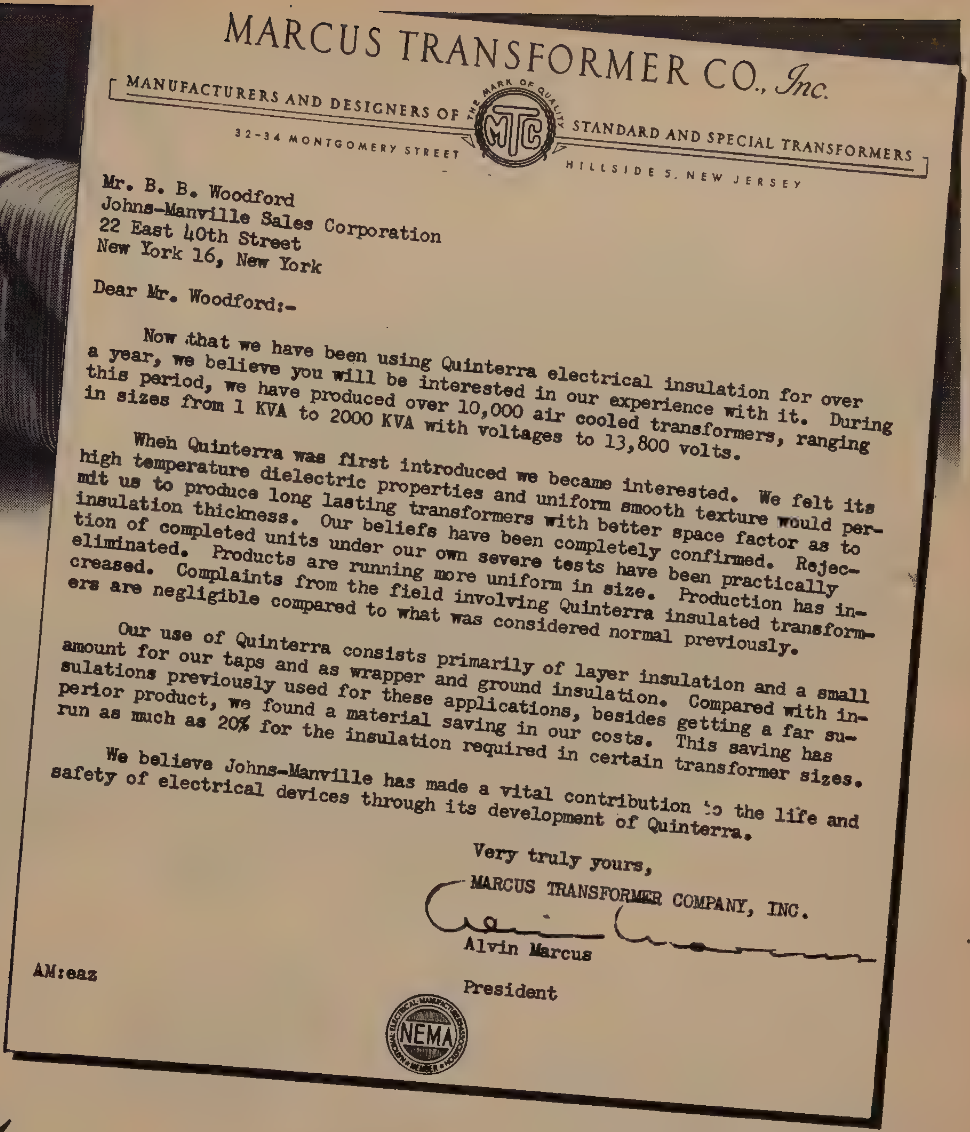
Motor-starting Capacitor



A new addition to a line of Bakelite cased capacitors desig specifically for motor manufacturers who are in need of an el trolytic capacitor that will fit into a small space. This capacit Type ETW, is only $1\frac{7}{16}$ in. in diameter and 2¾ in. long. Desp its small size, it is available in capacities up to 150 mfd at volts a-c. The capacitor can be used whenever the starting cy does not exceed 60 one-second starts per hour, or its equivalent *Cornell-Dubilier Electric Corp., South Plainfield, N. J.*



uinterra, type 6, being used as
nterlayer insulation in a Marcus
istribution transformer.



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New York 16, New York

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Now that we have been using Quinterra electrical insulation for over a year, we believe you will be interested in our experience with it. During this period, we have produced over 10,000 air cooled transformers, ranging in sizes from 1 KVA to 2000 KVA with voltages to 13,800 volts.

When Quinterra was first introduced we became interested. We felt its high temperature dielectric properties and uniform smooth texture would permit us to produce long lasting transformers with better space factor as to insulation thickness. Our beliefs have been completely confirmed. Rejection of completed units under our own severe tests have been practically eliminated. Products are running more uniform in size. Production has increased. Complaints from the field involving Quinterra insulated transformers are negligible compared to what was considered normal previously.

Our use of Quinterra consists primarily of layer insulation and a small amount for our taps and as wrapper and ground insulation. Compared with insulations previously used for these applications, besides getting a far superior product, we found a material saving in our costs. This saving has run as much as 20% for the insulation required in certain transformer sizes.

We believe Johns-Manville has made a vital contribution to the life and safety of electrical devices through its development of Quinterra.

Very truly yours,
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Alvin Marcus
President

AM:eaz

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—And it tells about actual savings d customer satisfaction in typical perations with this flexible, continuous sheet insulation. Quinterra is being widely used for interlayer and wrapper insulation in transformers and coils. Its lasting dielectric strength assures a greater safety factor and longer operating life. Quinterra withstands higher temperatures than the hot-spot limit of 130C for Class B insulations.

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- ✓ reduces complaints
- ✓ improves production rate
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Motor manufacturers know that well. Designing for efficiency, they take special care in their specifications for anti-friction bearings.

They know, too, that when they specify SKF bearings, they are taking advantage of all the experience available only from *pioneers.* They know there are good reasons why they can expect SKF bearings to be uniform, dependable, exactly right for whatever job there is to do of minimizing friction. **SKF** INDUSTRIES, INC., PHILADELPHIA 32, PA., *the pioneers of the Deep Groove Ball Bearing, Spherical Roller Bearing, Self-Aligning Ball Bearing.* 7030

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BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW *for domestic delivery; none sent on approval.)*

PHENOMENA, ATOMS AND MOLECULES

Irving Langmuir—Philosophical Library, New York. 1950. xi + 436 pp. $10.00.

This book, prefaced by the author's five-page introduction, consists of reprints (arranged by subject mattter) of twenty of Dr. Langmuir's papers, chosen from among the 200 and more that he has published since joining the Research Laboratory of the General Electric Company in 1909. The earliest of the reprinted papers, "The Dissociation of Hydrogen Into Atoms," was originally published with G. M. J. Mackay in 1914; the latest, "World Control of Atomic Energy," first appeared in 1946. The titles of some 180 papers listed at the end of the book display the extraordinary scientific productivity of the author and the wide range of his interests. The reprinted papers reveal, at least in part, the workings of the mind of a master reasoner gifted with a remarkable insight.

The publishers' blurb and the subtitle, which reads "An attempt to interpret phenomena in terms of mechanisms or atomic and molecular interactions," gave this reviewer the impression that the book would have a greater unity than it in fact possesses. A subtitle like "Twenty selected papers by Irving Langmuir" would have been more accurate. The space given to the author's ideas concerning convergent and divergent phenomena in science and society seems inadequate. Let us hope that Dr. Langmuir may find the time soon to present these important and timely ideas more fully.

V. ROJANSKY

MOTOR OILS AND ENGINE LUBRICATION

Carl W. Georgi—Reinhold Publishing Corp., New York. 1950. 514 pp. $8.50.

Mr. Georgi has rendered a valuable service in gathering together in most readable form technical information on motor oils and motor-oil specifications, together with a wealth of information on the service characteristics of motor oils in passenger-car and truck engines. This book can be useful to most operators; for example, the effect of oil properties on gasoline mileage and oil mileage is thoroughly treated, with ample substantiating evidence. The treatment is practical and timely, with no attempt to cover the theoretical aspects of chemistry, chemical engineering, and mechanical engineering involved.

DONALD F. WILCOCK

APPLIED EXPERIMENTAL PSYCHOLOGY

Alphonse Chapanis, Wendell R. Garner, and Clifford T. Morgan—John Wiley & Sons, Inc., New York (Chapman & Hall, Ltd., London). 1949. xi+434 pp. $4.50.

Here is a forerunner in the description of human factors in engineering design, written in an unusually easy, conversational manner, well illustrated and readily comprehendible.

It increases our awareness and understanding of the interdependent functions of the nervous and muscular systems; presents a fine statistical study of the human capacities to perceive, to work, and to learn; and then proceeds to teach us how these physiological and psychological phenomena can best be applied to the more efficient engineering design and operation of machines for human use.

The authors have compiled, analyzed, and correlated great volumes of data from their fine lists of references on statistics, biotechnology, biomechanics, psychoacoustics, human engineering, applied psychophysics, engineering psychology, and systems research on the latest discoveries of how we see, hear, speak, move, and work, and have applied them to the more efficient design of visual displays, instrument panels, signalling systems, manual controls, and working environments, all in a concise, easy manner. There is, in addition, at the end of each chapter a brief summary of its contents and a frank and sincere appraisal of the material based on broad and varied studies and experiences in the field.

ARNOLD H. HOFFER

PATENT PRACTICE & MANAGEMENT

Robert Calvert—Scarsdale Press, Scarsdale, N. Y. 1950. xii + 371 pp. $5.00.

A practical guide to patent questions, written in an easy, conversational tone for the benefit of the perplexed inventor or executive. Probably because of the author's own background, more space is given to situations and examples involving chemistry and processes than is usual in most books of this nature.

As they affect patents, phases of work by people concerned with research, development, and the management thereof are well covered. Although the legal technicalities of licenses, assignments, patent applications, and infringement suits are not analyzed in detail except to the extent necessary for general understanding of these aspects of patent work, the book does contain an appendix of forms as well as a useful glossary of terms relating to patent matters.

CHARLES C. ALLYN

HOW TO BECOME A RADIO AMATEUR (11th Edition)

American Radio Relay League, West Hartford, Conn. 1950. 58 pp. $.50.

Always a favorite with the radio neophyte, this beginner's guide to the hobby of amateur radio bears little resemblance to former editions. The radio receivers and transmitters described here are suitable for any newcomer, but they have been especially designed with an eye toward the new Novice Class of amateur license which the F.C.C. proposes to make available by next year.

The basic-theory section is brief but quite ample for the needs of a beginner. Special care has been taken to familiarize the beginner with schematic symbols, and a two-page spread shows pictures of various radio components with their proper symbols.

The book covers practically every subject of interest to a radio beginner, and its lucid presentation recommends it to anyone interested in becoming a radio amateur.

G. H. FLOYD

MATRIX ANALYSIS OF ELECTRIC NETWORKS

(Harvard Monographs in Applied Science, No. I)

P. Le Corbeiller—Harvard University Press, Cambridge (Mass.) & John Wiley & Sons, Inc., New York. 1950. xi+112 pp. $3.00.

To say that the work of Kron has been neglected would be to give a misleading impression of the true state of affairs. That his ideas have not yet found a place in the regular engineering curriculum may properly be classified as neglect. So, too, may the general disinclination of practicing engineers to make use of the concepts and methods that Kron has pioneered for the past fifteen years. But neglect is hardly the word for the many bitter criticisms that have been levelled against his work.

(Continued on following page)

All the more welcome, then, is this book by a man who has thought deeply on the matter and is not afraid to express the opinion, in his preface, that Kron's tensor theory "is the most significant advance in electrical engineering analysis since the introduction of impedances by Kennelly and Steinmetz and of the two-reaction method of A. Blondel."

Professor Le Corbeiller has given a persuasive and elegant introduction to Kron's ideas that should please both the engineers and the mathematicians. His strategy is subtle; by confining himself to relatively simple problems in stationary networks, he presents the fundamental technique of computation without bringing in the deeper, tensorial aspects of the theory, feeling that the reader who has once experienced the power of the method will himself look deeper into the subject.

While the book is fundamentally practical, in the sense that it shows how to apply Kron's method to simple stationary networks, the theoretical aspects are by no means neglected. On the contrary, the proofs of the basic transformation equations are models of lucidity, and the whole treatment reflects a searching examination of fundamentals by the author and a felicitous approach to pedagogical problems. As an elementary introduction to Kron's theories the book is without an equal.

BANESH HOFFMANN

STRENGTH OF PLASTICS AND GLASS

R. N. Haward—Cleaver-Hume Press Ltd., London (Distrib. by Interscience Publishers, Inc., New York). 1949. viii+245 pp. $5.50.

Primarily concerned with the mechanical properties of organic plastics and glass, the author's main emphasis is on the presentation of factual material. The chapter headings are as follows: Strength Relations, The Static Strength of Plastic Materials, The Static Strength of Glass, The Deformation of Plastics and Glass, Hardness and Related Subjects, Some Characteristic Properties of Complex Materials.

A large number of topics are considered under each chapter heading. None of these topics is perused in detail, but those desiring more information can obtain it by referring to the large bibliography at the end of each chapter. The book is recommended as a reference for plastics technologists and others interested in mechanical properties of matter.

H. TRACY HALL

ELECTRONIC ENGINEERING MASTER INDEX: 1947-1948

Edited by John F. Rider—Electronics Research Publishing Co., Inc., New York. 1950. xiii+339 pp. $19.50.

This book is an extremely complete index of electronic articles appearing in both American and foreign magazines during 1947 and 1948. A list of the magazines cataloged, the yearly rates, and publisher's addresses, as well as a summary of the important patents in each field, comprise a useful reference work for any technical library. A complete listing of articles in the electronic field is provided by a series of three books by the publisher. Such an index, though somewhat expensive and bulky for general use in an engineering office, is highly recommended for the technical library, where a complete listing of pertinent literature is necessary.

J. A. LAURENT, JR.

VACUUM EQUIPMENT AND TECHNIQUES

Edited by A. Guthrie and R. K. Wakerling—McGraw-Hill Book Co., Inc. New York. 1949. xvii+264 pp. $2.50.

As stated in its preface, this book is one of a series which has been prepared as a record of the research work done under the Manhattan Project and The Atomic Energy Commission. Specifically it is concerned with the development and operation of the high-vacuum equipment made by the personnel of the University of California Research Laboratory.

The first chapter, devoted to fundamental considerations in vacuum practice, contains a review of the kinetic theory of gases as it applies to vacuum conditions. Theoretical treatment is not nearly as extensive as that in Dr. Saul Dushman's recent book but nevertheless it adequately covers continuously pumped systems.

Chapters dealing with the elements of vacuum systems, vacuum gages, materials, and equipment are written in a descriptive and nontheoretical manner most useful to designers of industrial vacuum systems. A chapter on leak-detection instruments and techniques outlines some of the more popular methods used in vacuum apparatus.

An appendix containing the characteristics of many commercially available products used in conjunction with vacuum apparatus will be useful to designers and vacuum-system operators.

R. A. KOEHLER

PHOTOELASTICITY: PRINCIPLES & METHODS

H. T. Jessop and F. C. Harris—Dover Publications, Inc., New York. 1950. 184 pp. $3.50.

The purpose as indicated by the authors, who are Professors at University College, London, is to serve engineers who make use of the photoelastic method of stress analysis. The aim was to write for the man "who has not an extensive mathematical knowledge," and this has been achieved, though some readers may have a different interpretation of "extensive" than the authors'.

The first third of the book deals with basic principles; half of this is concerned with optics, covering enough lens fundamentals and essential polarization theory for understanding the details of the equipment used on the photoelastic bench. The rest is concerned with practical aspects of the photoelastic method. One chapter is devoted to examples of stress analysis, worked through in detail in the text.

The book does not have a bibliography and there are very few references directly to the literature. It is a well-written introductory text in the subject and should be very helpful to those learning the techniques of the photoelastic method.

F. J. STUDER

REFLECTIONS OF A PHYSICIST

P. W. Bridgman—Philosophical Library, New York. 1950. xii+392 pp. $5.00.

This collection of 19 essays published during the period 1929–1949, together with three papers here presented for the first time, comprises the bulk of nontechnical writings of the author. A few of the papers deal with the philosophy of physics, a topic first presented by the author in his classical work, "The Logic of Modern Physics," in which he expounded his credo that physical concepts should correspond to feasible operations. Only experience should be our guide, and conceptual schemes should be regarded as pragmatic aids to thinking. Most of the papers deal with the scientist as an intelligent member of society and include such gems of profound exposition as "The Struggle for Intellectual Integrity," "Society and the Intelligent Physicist," and "New Vistas for Intelligence."

As might be expected, the essays are, to say the least, thought-provoking and should prove extremely stimulating. Some readers will probably differ from Bridgman's point of view regarding the pitfalls in a democracy; but the author has the courage of his convictions, as illustrated by his "Manifesto," issued in *Science* in 1939, in which he states, "I have decided from now on not to show my apparatus or discuss my experiments with the citizens of any totalitarian state [because these scientists are] no longer free individuals."

The volume can be heartily recommended not only to physicists but also to the intelligent layman, who will find in it an exposition of the scientific attitude with respect to both science and his social environment.

Saul Dushman

Infrared Radiation Therapy Sources and Their Analysis with Scanner

Leopold Rovner—Charles C. Thomas, Publisher, Springfield (Ill.). 1950. 34 pp. $1.50.

This short monograph is a description of a radiation-analysis apparatus and qualitative data taken on several types of infrared sources. While relative distribution patterns are given and may be intercompared, no quantitative data on lamp output is given. Lamp units of both the internal and external reflector type are evaluated along with ceramic, Carborundum, bare-wire, and sheathed radiator source units.

The book adds very little to knowledge and techniques in use by manufacturers of sources for infrared therapy. However, the physical therapist will find it a useful guide in the discreet application of infrared sources.

A. H. Canada

Molecules and Crystals in Inorganic Chemistry

A. E. Van Arkel (Transl. by J. C. Swallow)—Interscience Publishers, Inc., New York (Butterworths Scientific Publications, Ltd., London). 1949. 234 pp. $3.85.

The dust wrapper describes this as a book for students of science, giving "a wide insight into inorganic chemistry by means of a thorough study of the heteropolar bond and the correlation of structure and properties which can be derived from it." The statement is no idle boast, but rather a sound prospectus for the pages which follow. For this is a book that attempts to tell "why." It is not a compilation of facts, a review of existing theories, but a simple, direct introduction into the relationship of physical and chemical properties with fundamental molecular structure.

A brief description of the periodic table is followed by a short chapter on the chemical bond. The ionic bond is introduced, and an excellent chapter on the properties of ionic compounds leads to a discussion of chemical reactions. Complex compounds are next taken up, then polarization; there is a chapter on water, and finally the nonelectrostatic bond.

The author has aimed high and has been quite successful. The result is an easily read, nonmathematical excursion into the realm of modern inorganic chemistry. The descriptive tables are especially good.

L. S. Moody

Physical Methods of Organic Chemistry: Part II (2nd Edition)

Edited by Arnold Weissberger—Interscience Publishers, Inc., New York (London). 1949. xi+1024 pp. $12.50.

The series of six volumes having the general title of "Techniques of Organic Chemistry" has as its purpose the fostering of rational use of the many tools available to the organic chemist. Volume I, dealing with Physical Methods, is divided into two parts of about 1000 pages each and contains a total of 31 chapters. The style of presentation is that of a very comprehensive laboratory manual. The actual techniques and apparatus are described and criticized. The chapters serve admirably in bringing to the reader's attention the scope and limitations of a variety of the available tools.

The present work covers x-ray and electron diffraction, refractometry, spectroscopy, and spectrophotometry, colorimetry and related subjects, polarimetry, determination of dipole moments, conductometry, electrophoresis, patentiometry, polarography, determination of magnetic susceptibility and radioactivity, and mass spectrometry. Those subjects in which considerable new information has been obtained since the first edition appeared in 1946 have been rewritten. The chapter on electrophoresis is new.

The present volume serves its purpose very well and is recommended both to students desiring to gain knowledge of the subjects covered and to chemists desiring a critical evaluation of a method along with practical suggestions for its use.

J. R. Elliott

Index of Nomograms

Douglas Payne Adams—Technology Press, Massachusetts Institute of Technology; John Wiley & Sons, Inc., New York (Chapman & Hall, Ltd., London). 1950. viii+174 pp. $4.00.

Over 1700 nomograms, published in scientific periodicals since the 1920's, are tabulated in this new Index. The subject matter represented includes all fields of engineering and mathematics as well as medicine, food, textiles, etc. The book is well arranged in two parts: a Master Index listing the nomograms by subject, with a brief description of the contents and giving the reference to the periodicals; and a Key Word Index, an alphabetical listing of the nomograms, cross-referenced to the Master Index.

There is no question that these nomograms are of great value to the engineer trying to set up a complex repetitive design procedure. However, since this is merely an index of the nomograms and must be used in combination with an extensive periodical collection, it would be most useful on the reference shelf of a technical library.

Henry Lehmann

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ON ARTICLES IN OTHER TECHNICAL JOURNALS

METAL CUTTING

Determining the Machinability of Metals. Gerald Lewis. *Mach.*, July 1950; v. 56, p. 152.

Describes the MSE-Schlesinger machinability tester, which measures the specific cutting resistance and the abrasive effect of the material.

"Super Machining" Steels Increase Production 100%. E. F. Ross. *Steel*, July 31, 1950; v. 127, p. 60.

The properties of improved free-machining Bessemer and lead-bearing rephosphorized and resulphurized open-hearth steels.

RADIO ENGINEERING

Balanced Rectifier Modulators Without Transformers. D. G. Tucker. *Electronic Engng.*, Apr. 1950; v. 22, p. 139.

Some simple rectifier modulators are described which give balance against carrier leak but avoid the use of transformers.

Induced Grid Noise. R. L. Bell. *Wireless Engr.*, Mar. 1950; v. 27, p. 86.

It is shown that under favorable conditions there is an exact relationship between mean-square noise currents induced at the grid of a triode valve and the "space-charge" component of input capacitance measurable at that point.

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White-noise Testing Methods. Emory Cook. *Audio Engng.*, Mar. 1950; v. 34, p. 13.

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ELECTRIC MOTORS

Motors for Integral Mechanisms. Thomas T. Woodson. *Mech. Engng.*, Aug. 1950; v. 72, p. 615.

The basic properties of motors as applied to built-in mechanisms.

Significant Progress in Lubrication. R. A. Hutchins. *Ry. Age*, July 8, 1950; v. 129, p. 29.

Describes the lubrication of traction motors on diesel-electric locomotives.

AMPLIFIERS

Dynamoelectric Amplifiers. R. M Saunders. *Elec. Engng.*, Aug. 1950; v. 69, p. 711.

This article serves to collect in one place the basic theoretical principles of all types of dynamoelectric amplifiers.

Static Magnetic Amplifier for Regulating Circuits. H. E. Larson and T. Dunnegan, Jr. *Iron & St. Engr.*, July 1950; v. 27, p. 88.

Describes the operation and application of magnetic amplifiers.

CAMERAS

Calibration of Precision Airplane Mapping Cameras. Francis E. Washer and Frank A. Case. *Nat. Bur. Stds. Jour. Res.*, July 1950; v. 45, p. 1 (RP No. 2108).

Describes an instrument to calibrate an airplane camera by permitting the registration of all necessary information on a single negative.

High-temperature X-ray Diffraction Camera. H. J. Goldschmidt and J. Cunningham. *Jour. Sci. Instr.*, July 1950; v. 27, p. 177.

A versatile 19-cm x-ray diffraction camera, designed to operate up to at least 1400 C, is described.

FOUNDRY PRACTICE

Applied Hydraulic Theory Improv
Casting Technique. James A. Clar
Iron Age, July 20, 1950; v. 166, p. 90.

How controlling metal pouring to confor
to the solidification rate has improve
centrifugal casting output at Waterto
Arsenal. Also applies to ingots and san
castings.

Castings Improved by the Use
Graphite Molding Material. Vladim
A. Grodsky. *Metal Prog.*, July 1950; v. 5
p. 60.

Describes a chilling graphite molding mi
ture which has been developed, havi
the properties of a good ordinary moldi
sand and a much higher heat condu
tivity. Cost is low, especially when o
broken crucibles are the source
graphite.

AIR CONDITIONING

Analysis and Influence of Climatolo
Upon Air-conditioning Design. Jo
Everetts, Jr. *Refrig. Engng.*, July 195
v. 58, p. 649.

Climate effects on the air-conditioni
load are studied for three entirely di
ferent types of structures in three wide
separated cities.

Useful Tool—Properly Engineere
Evaporative Cooling. Frank W. S. Hu
ton. *Heat. Piping & Air Cond.*, July 195
v. 22, p. 96.

Explains details of design and applic
tion of this type of equipment.

GAS TURBINES

Characteristics of Disk-controlle
Flame. E. A. DeZubay. *Aero Digest*, Ju
1950; v. 61, p. 54.

A study of maintaining a flame in t
reheat burners of gas turbines and ra
jet burners.

Machining Aircraft Turbine Blade
Mach., July 1950; v. 56, p. 155.

Describes the machining of nimonic all
blades by an aircraft company.

Will the Low-priced Car Be Turbin
Powered? Henry C. Hill. *Auto Ind.*, Ju
15, 1950; v. 103, p. 41.

Covers the practical aspects of using g
turbines in automobiles.

FLUID FLOW

Boundary Layer in the Convergin
Nozzle of a Swirl Atomizer. G. I. Taylo
Quar. Jour. Mech. & App. Math., Jun
1950; v. 3, p. 129.

Theoretical study of flow phenomena
atomizer jets such as those used in o
fired furnaces.

On the Linearized Theory of Supe
sonic Flows Through Axially Sy
metrical Ducts. I. Kolodner. *Commu
on Pure & App. Math.*, June 1950; v.
p. 133.

The behavior of an inviscid, compressib
fluid entering an axially symmetrical du
of slowly varying cross section, with
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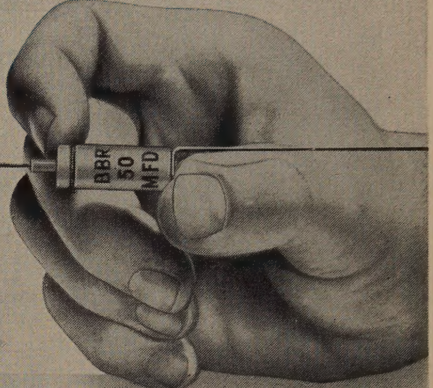

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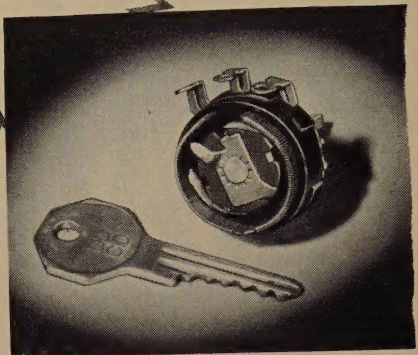

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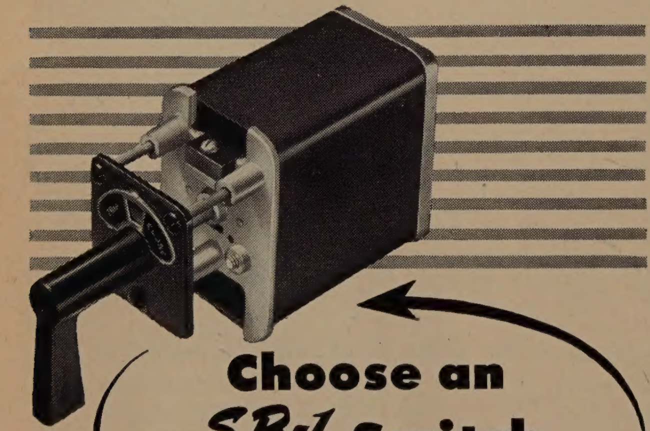

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MEASURING INSTRUMENTS

IMPROVED PHOTOMULTIPLIER TUBE COLOR DENSITOMETER. Monroe H. Sweet. *Soc. Motion Pict. & Telev. Engrs. Jour.*, Jan. 1950; v. 54, p. 35.

Describes an instrument intended especially for the measurement of color in connection with colored motion pictures.

PRECISION MEASUREMENT OF ROTARY MOTION. H. J. Finden. *Electronic Engng.*, Jan. 1950; v. 22. p. 2.

Describes electronic methods of measuring revolutions per minute.

RADIATION PYROMETER FOR LOWER TEMPERATURES. Sam Tour. *Iron Age*, May 18, 1950; v. 165, p. 90.

Tinplate temperatures between 180 and 400 F can be measured with this newly developed instrument.

HOW TO REPAIR TOOLS BY ATOMIC-HYDROGEN WELDING. R. J. Tierney. *Iron Age*, Apr. 13, 1950; v. 165, p. 86.

Describes welding without destruction of heat-treated properties, by the use of the high-temperature shielded flame.

PLASTICS

APPLICATION OF LOW-LOSS PLASTICS. John Delmonte. *Elec. Mfg.*, May 1950; v. 45, p. 80.

A "re-evaluation" of the design significance of dielectric properties and of the factors that influence the behavior of low-loss plastics.

CROSSHEAD EXTRUSION OF THERMOPLASTICS. E. G. Fisher. *Modern Plastics*, May 1950; v. 27, p. 83.

Developed during the war to make wire and cable insulation, this method, coupled with multiple-screw extruders, is now producing many unusual end products.

LABORATORIES

DESIGN AND CONSTRUCTION OF A SMALL RADIO-ACTIVITY LABORATORY. Luther E. Preuss and John H. L. Watson. *Nucleonics*, May 1950; v. 6, p. 11.

The authors describe how they set up a laboratory for general-purpose work on a limited budget. The ideas presented can be applied to erection of a laboratory for basic research, hospitals, and industry.

NUCLEAR ENGINEERING IS CHEMICAL ENGINEERING. W. E. Winsche. *Chem. Engng.*, May 1950; v. 57, p. 161.

Discusses the application of chemical engineering in the development of nuclear energy for such problems as heat exchange, isotope separation at high yields, and the recovery, concentration, and storage of radioactive wastes.

JET PROPULSION

AIR-TRANSPORT POWERPLANTS AFTER 1955. Winnett Boyd. *Aero Digest*, May 1950; v. 60, p. 18.

Considers the future development of air-transport powerplants.

MATERIALS-SUBSTITUTION PLAN FOR TURBOJETS. *Aviation Week*, May 8, 1950; v. 52, p. 27.

Offers a program covering substitution for the critical components of turbojet engines.

ELECTRIC CURRENT RECTIFIERS

MECHANICAL RECTIFIER. Otto Jensen. *Iron & St. Engr.*, Apr 1950; v. 27, p. 69.

Lists advantages offered below 400 volts by this rectifier which warrant investigation by prospective users.

LOCOMOTIVES

ECONOMICS OF DIESEL-ELECTRIC MULTIPLE-UNIT TRAINS. H. Bleibtreu. *Ry. Age*, Apr. 22, 1950; v. 128, p. 786.

A study of the possibilities of improving suburban-type passenger service with a reduction of operating expenses.